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Shift Work, Age, and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities II. Laboratory Performance Measures

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16. Abstract

Many Air Traffic Control Specialists (ATCSs) work a counterclockwise rotating shift schedule, called the "2-2-1," or some variation of the schedule. The 2-2-1 involves rotating from two afternoon shifts to two mornings, and finally, to a midnight shift over the course of one work week. The purpose of the present study was to investigate the effects in two different age groups of working the 2-2-1 schedule, as compared to a straight day schedule on measures of complex task performance in a laboratory-based synthetic work environment. It was hypothesized that the counterclockwise rotations would result in performance decrements over the course of the 2-2-1 week. Four groups of five male subjects between the ages of 30 to 35 (n=10) and 50 to 55 (n=10) participated in the four-week study. Subjects were screened on medical and cognitive criteria. The Multiple Task Performance Battery (MTPB) was utilized to provide a motivating synthetic work environment. Subjects worked three 2-hour sessions on the MTPB per eight-hour day for three weeks of a four-week protocol. During the second and fourth weeks, subjects worked day shifts (0800-1630). During the third week, subjects worked the 2-2-1 schedule. Performance measures were analyzed for each of the five tasks in the MTPB. Composite scores were also computed. Significant performance decrements were observed primarily on the night shift for both age groups. The older group demonstrated decrements in accuracy of recall on the code lock task following both rapid rotations during the 2-2-1 schedule. This study was part of a research program designed to develop fatigue countermeasures for Air Traffic Control Specialists. The hypothesis that the rapid, counterclockwise rotations would result in performance decrements was partially supported. Data suggest that initial interventions should be directed toward maintaining alertness and performance on the night shift.

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Shift Work, Age, and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities
II. Laboratory Performance Measures

INTRODUCTION

This report is the second in a series on the findings from a study on the 2-2-1 shift schedule used in the Federal Aviation Administration's (FAA) air traffic control facilities. The 2-2-1 is a counterclockwise, rapidly rotating shift schedule that requires employees to work two afternoon shifts, followed by two morning shifts, and finally, a night shift, within a five-day period (Price & Holley, 1990). Little evidence was available in the literature about the relationship between performance and counterclockwise, rotating schedules.

This laboratory-based study was designed to empirically investigate the extent to which the 2-2-1 schedule resulted, or failed to result, in sleep and circadian rhythm disruption, performance decrements, and changes in subjective measures of sleepiness and mood. Age was investigated as a factor in the study utilizing two different age groups to examine the response to the shift schedule. The background on the research issues related to air traffic control specialists (ATCSs) and the sleep data was provided in the first report of this series (Della Rocco & Cruz, 1995). This report presents data on the performance measures.

The ATCS's job requires complex cognitive performance. This includes activities such as monitoring complex traffic patterns to ensure aircraft separation through application of established rules and procedures, resolution of potential aircraft conflicts, traffic sequencing, assessing developing weather patterns, and providing appropriate adjustments to routing. In 1987, Computer Technology Associates, Inc. (CTA) completed a job task analysis. They identified 14 cognitive/sensory attributes required for performing the tasks of extreme or high criticality associated with performance of computer and radar workstation jobs in the current ATC system. These included coding, movement detection, spatial scanning, filtering, image/pattern recognition, decoding, visualization, short-term memory, long-term memory, deductive reasoning, inductive reasoning, mathematical/probabilistic reasoning, prioritizing, and verbal filtering. Many of these cognitive abilities have demonstrated circadian variations and susceptibility to circadian disruption (Monk, 1990). Therefore, an ATCS's performance of tasks requiring these specific skills and abilities could be expected to 1) demonstrate circadian variability and 2) be susceptible to the disruptive effects of shift work on circadian rhythms.

Several theoretical lines of investigation relate to the question of the relationship between age and performance of complex tasks under a stressor such as shift work. Specifically, these include circadian rhythms (biological, sleep/wake, and performance), disruption of those rhythms due to shift work, and their relationship to an employee's performance.

Performance Rhythms

Evidence of time-of-day effects associated with performance dates back to the late 1800s and early 1900s. Research on biological rhythms during this century has elucidated some of the parameters of these effects. A review of this research follows with particular attention paid to the types of tasks used to measure performance in the present study.

Ebbinghaus (1885) reported that learning nonsense syllables was more rapid in the morning (cited in Colquhoun, 1982). Other researchers of the same era reported that slowest speed occurred in the afternoon (cited in Colquhoun, 1982). Thus, by the end of the 19th century, a pattern was described in which performance was found to be better in the morning (sometimes with a "warm-up" period required), while a trough in performance was described after the midday meal in the afternoon.

Gates (1916) conducted a series of studies addressing the optimal time of day for teaching academic subjects (cited in Colquhoun, 1982). Gates

reported a distinction between the more "strictly mental" processes and the more "motor" functions. Performance on mental activities reached a maximum later in the morning and showed decrements in the afternoon. Performance of motor tasks, however, demonstrated a continuous increase in efficiency over the course of the day. "Mental fatigue" that accrued over the course of the day was postulated to be the controlling mechanism for the observed decline in mental performance.

A major researcher to address the issue initially in the 1930s, was Kleitman (1963). Kleitman reported a rise in performance from early morning to a peak in the afternoon and then a decline toward the evening hours. Concurrent body temperature measurements that tracked the performance patterns suggested to Kleitman that there was a causal relationship between the two (Folkard & Monk, 1985). Thus, he proposed the Basic Rest-Activity Cycle (BRAC) theory. Kleitman utilized simple repetitive tasks (e.g. card dealing) for these studies. Many studies after Kleitman focused upon the parallel relationship between various performance measures and the circadian temperature curve (Folkard & Monk, 1985).

However, at least two lines of evidence ran counter to such a simplistic relationship (Folkard & Monk, 1985). The first was the "post-lunch dip," an observed decline in performance following the midday meal. The second was a decrease in performance over the day on memory tasks such as digit span. Blake (1967) investigated performance rhythms in a number of "immediate information-processing tasks" (cited in Colquhoun, 1982). These tasks included card sorting, vigilance, letter cancellation, serial reaction time, calculations, and digit span. Blake demonstrated that performance appeared to track the increase in body temperature (apart from a post-lunch dip in performance) on all tasks except digit span. Peaks in performance on all other tasks were found to reach a maximum around 2100, which coincided with the peak in body temperature. Performance on digit span, however, peaked in the morning and showed a continuous decline over the course of the day, with the lowest measures found around 2100.

Folkard and Monk (1985) reviewed studies on working memory. They characterized working memory tasks as involving both short-term storage and the processing of information. Therefore, such tasks might be expected to show a different pattern than short-term memory tasks alone. In fact, data from Laird (1925) on mental arithmetic (cited in Colquhoun, 1982) and Folkard (1975) on two verbal reasoning tasks demonstrated a pattern in which peak performance was found around midday. Task demands were found to impact the findings, however. Folkard systematically varied the memory load involved with a visual search task. Performance on the visual search task in a low load condition paralleled the daily curve of body temperature. However, with increasing memory load, the peak shifted toward earlier in the day and was reversed in the high load condition compared to the low load condition. Folkard and Monk (1985) found that performance on more complex tasks of immediate memory, requiring subjects to recall information presented in passages of prose, declined over the day.

Rutenfranz, Aschoff, and Mann (1972) found signal detection and mean response time to signal detection to parallel the course of the body temperature rhythm. Klein and Wegmann (1974) measured psychomotor, cancellation, addition, and flight simulator performance over 124 hours. They found that these measures also appeared to parallel body temperature.

These studies demonstrated a variety of circadian performance rhythms that can vary with changing demands of the task. The degree to which the variations have practical significance has been questioned by Damos (1989). In a selective review of circadian effects on simple information processing tasks for the Navy, she concluded that the effect did not appear to be large but, due to methodological problems in existing studies, the extent of the effects may have been masked. She noted three common methodological flaws in this kind of research: 1) failure to train subjects on a task before collecting data, thereby confounding any time-of-day effect with practice effects; 2) assuming equivalence of subjects' circadian cycles; and 3) failure to

control subjects' meal times or the content of meals, thereby ignoring the potential confound of a possible "post-lunch dip" in performance. Monk (1990) echoed Damos' criticism regarding practice effects and added that, "... differences in such chance factors as the subjects' motivation, perception of the task, and distraction by some non-task event, can render performance measurement notoriously inaccurate" (p.186). He characterized the circadian performance rhythms, however, as non-trivial, robust fluctuations of significant magnitude, when adequate care is given to methodological measurement problems.

Phase Shift Studies

The relationship between circadian rhythm disruption and performance has been examined in phase shift studies that were designed to modify the phasic relationship between circadian rhythms and time. A review of the literature was provided in more detail in the first report of this series (Della Rocco & Cruz, 1995). In a series of studies, Taub and Berger (1973) phase-shifted sleep periods and examined effects on performance. Compared to baseline sleep periods, phase-shifted experimental conditions resulted in performance deficits on two tasks, calculation and vigilance. Other studies, particularly those on jet-lag (Wegmann & Klein, 1985; Monk, Moline, & Graeber, 1988) indicated that interruptions of sleep were more detrimental to performance than sleep loss.

Of particular interest to the present study were the investigations of researchers from the FAA's Civil Aeromedical Institute during the mid-1970s. The Multiple Task Performance Battery (MTPB) provided a synthetic work environment in which the influence of various stressors, such as a phase shift of the sleep/wake cycle, on complex task performance could be systematically investigated in the laboratory. Higgins, et al. (1975) reported the effects of a 12-hour phase shift in the work day. Performance on the MTPB revealed that decrements in performance were found on the day following the short three-hour sleep period; an 8% drop from the first session of the day to the last. In addition, performance on the first three days following the phase shift was relatively high during four of the five one-hour MTPB sessions, but fell off significantly during the last session. The end-of-the-day drop in performance was eliminated by days 4-6 after the phase shift, with little variation across each day. A reversal of the diurnal pattern of performance was shown during the last three days of the study such that the performance peak after the phase shift was shifted 12 hours from the pre-phase shift peak. MTPB scores were lower, in general, on the last three days of the study, probably as a result of an end-of-the-study effect.

In a follow-up study, Higgins, et al. (1976) explored a laboratory analog of both a six-hour phase advance and a six-hour phase delay. Performance on the MTPB revealed that the phase-advanced group had the greatest deficit in performance while the phase-delayed group had the best post-phase-shift performance. However, there was a confound in the number of hours slept after the "flight" to London, making it difficult to generalize these effects.

A Simulated Work Environment—The Multiple Task Performance Battery

Time-sharing ability and the ability to perform under varying workloads are critical to performance in both the cockpit and air traffic control. The MTPB was established to provide a laboratory approach to studying complex performance under these conditions. The MTPB provides a motivating synthetic work environment in which workload can be varied and performance under different experimental conditions can be measured. Originally developed to study the performance of air crews, the battery is well known in the performance literature through the work of researchers such as Alluisi, Chiles, Adams, Mertens, and Morgan.

In 1956, the Aerospace Medical Research Laboratories at Wright-Patterson Air Force Base began a program of research on crew performance in aircraft applicable to advanced systems of the future (Chiles, Alluisi, & Adams, 1968). At that time, the United States Air Force (USAF) was developing aircraft nuclear propulsion (ANP) that would provide a greatly-increased range of flight operations. The

target flight duration for the ANP program was set at five days. Although the resulting life support requirements had been addressed in ground and sea operations, such problems had not been addressed in the cockpit. The resulting additional weight in an airborne system was a critical factor. Thus, the human factors (such as minimum number of crew members, maximum duration of missions, and work/rest schedules) of such an increase in flight time needed to be investigated. Because no specific advanced aircraft system was to be simulated directly, the line of research led to an approach to studying multiple-task performance of synthetic work in controlled laboratory situations. In 1968, Chiles et al. presented a summary of their eight-year research program on the performance effects of various work/rest schedules during confinement in a simulated aerospace vehicle crew compartment. The MTPB, the task battery utilized in the program to provide the synthetic work environment, was found to be a reliable, face-valid, sensitive technique for assessing complex operator performance.

The goal of the measurement process in the Wright-Patterson research was to permit detection of operationally important changes in operator performance as a function of the requirements of an extended mission. Thus, decrements should be meaningfully relatable to critical operational tasks in the cockpit that affect operator reliability, safety, and success of the mission. To meet these goals, the measurements had to be related to functions that are required in the performance of operational tasks. The determination of the measurements to be used had to be based upon an analysis of the tasks performed in the operational environment. Chiles, et al. (1968) categorized the functions required in an aviation related environment into the following five categories: 1) monitoring a system's status; 2) making discriminations among various stimuli presented by display indicators; 3) operating on or storing information received from displays; 4) operating various controls to correct deviations from desired conditions, to change existing conditions, and to remove errors; and 5) communicating by transmitting and receiving information from other individuals in the system. In addition, time-sharing, or the ability to distribute attention and action over multiple displays and activities, was also identified as necessary.

Selection of the specific tasks for the battery was initiated in a review of the existing human performance literature. Chiles and associates concluded that research at that time contributed only to general guidelines, and that the selection would need to be derived from task analysis for functions of interest. Criteria were set for the tasks that dealt with psychometric properties, as follows: 1) the tasks should be defensible as measures of functions performed by an operator in advanced aviation-related systems; 2) the tasks must appear to the subject to measure important, valid functions; 3) the tasks had to have good test-retest reliability; 4) the tasks should be orthogonal, to the extent that the operator functions were assessed as independent processes; 5) the task needed to be sensitive to important, or "real" in an applied sense, performance deficits; and 6) reasonable training periods should result in asymptotic levels of performance.

Thus, the following set of tasks, which demonstrated high reliability with relatively minor training requirements and allowed for the study of a relatively broad range of workloads, was selected for the MTPB. Detailed descriptions of the tasks in the current battery are provided in the methods section of this paper; however, the original tasks included:

1) Monitoring static processes. This category related to the operational environment, within which an operator was concerned with assuring that no malfunction or other type of emergency had occurred by scanning a display, lights, or dials. This measured the operator's perceptual recognition of a non-normal state. In the original battery, this included red and green lights, as well as an auditory task.

2) Monitoring dynamic processes. In this task, the indicators exhibited dynamic continuous changes. The operator determined whether or not the fluctuating process was within prescribed limits. This measured the operator's perceptual recognition and dynamic monitoring abilities.

3) Stimulus discrimination (target identification). The operator was required to make simultaneous or successive comparisons of stimuli, and judge the similarity or differences of one or more parameters of the stimuli.

4) Information processing (arithmetic computation). Operators in an aviation-related environment must carry out a variety of tasks that require processing information received from various kinds of displays. Mental computation is common to a number of the tasks. Therefore, mental arithmetic was chosen as the information processing task. It required short-term memory involved in sequential mental operations, and long-term memory required for mental arithmetic operations. It was also identified as a means of using up "mental channel capacity."

5) Procedural performance (code-lock). This provided a measure of the operator's ability to carry out procedures, and problem solving. In the original battery, this was a group coordinated activity and involved communication among "crew members."

Chiles, et al. (1968) reported the results from 13 studies and 139 subjects, conducted over an eight-year period. Among their findings were: 1) performance on the battery of tasks reached asymptote after 48 hours of practice, 2) test-retest reliabilities for the tasks were very good, and 3) when performance was measured around-the-clock, diurnal variations in performance tended to parallel variations in psychophysiological measures.

Use of the MTPB allows the investigation of Knowles' (1963) theories of measurement of workload. One of Knowles' theories stated that an efficient way to assess workload was through the effect of performance of a task of primary interest to the subject on the subject's performance of a secondary task. Thus, with the MTPB, the monitoring tasks provide secondary "passive" tasks, against which the addition of primary "active" tasks (mental arithmetic, code lock, and target ID) can be assessed.

Significant differences between 15-minute segments were reported by Chiles, et al. (1968) in performance of the monitoring tasks alone, versus the full battery. In summary, the monitoring data indicated that working on the entire battery of tasks constituted an increased workload relative to the monitoring tasks alone. The heaviest workload was found in the arithmetic with code lock and target ID with code lock conditions.

By 1968, Chiles was employed by the FAA at CAMI. Over the next decade, Chiles conducted a number of studies with the MTPB, investigating parametric dynamics of such variables as signal presentation rates for both the static and dynamic warning lights, and the investigation of the existence of a separate time-sharing ability.

Finally, Chiles, Jennings, and West (1972) and Chiles and West (1974) examined the MTPB as a predictor of the potential of ATCSs to successfully complete the FAA Academy nonradar training program, and succeed in field training. This pair of studies demonstrated the predictive validity of the MTPB measures for Academy training and subsequent retention/termination status of trainees 2-2.5 years post-hire.

The MTPB has continued to be a valuable research tool as a synthetic work environment for studies of the effects of various stressors on complex task performance (Collins, Mertens, & Higgins, 1987; Collins & Mertens, 1988). The present study introduced a new, graphical CRT implementation of this battery. This version of the battery included monitoring of red and green warning lights (static stimuli), monitoring of probability meters (dynamic stimuli), mental arithmetic, target identification, and code lock solution and recall.

Research Hypotheses

Based upon the review of the literature, the following hypotheses were generated for investigation in the present study:

1) There would be a significant decrement in performance on complex tasks during the 2-2-1 work week because of the phase-advancing characteristics of the 2-2-1 schedule and the circadian performance trough on the night shift. Specifically, the following hypotheses were tested:

a) There would be a significant decrement in performance on the day after the first

"quick turn-around" (between the second afternoon shift and the first day shift) due to partial sleep loss and/or the phase-advancing properties of the 2-2-1.

b) There would be a significant decrement in performance on the night shift due to circadian performance troughs, cumulative partial sleep loss, the phase-advancing properties of the 2-2-1, and/or an interaction of all of these factors.

2) There would be an interaction between age and the adverse effects of shift work schedules on performance. Specifically, it was hypothesized that there would be a main effect of age on the analyses conducted on sleep and performance, such that the older group would show significantly greater effects of the 2-2-1 schedule. In addition, it was hypothesized that biochemical measures of the stressor effects of the 2-2-1 schedule would indicate that the older group experienced the schedule as significantly more stressful.

3) Performance measures would demonstrate a recovery period after resuming a day shift. Specifically, the following hypotheses were tested.

a) Performance scores on the first day shift after a 2-2-1 schedule would be significantly lower than the second afternoon shift of the 2-2-1 or subsequent days during the final week of day shifts.

b) The older subjects' performance scores would be significantly lower than the younger group's on the first day shift after a 2-2-1 shift and would take longer to recover.

METHODOLOGY

A four-week protocol was designed to investigate the effects of the 2-2-1 quick-turn-around schedule. The first week of the protocol was allocated for subject adaptation to wearing physiological monitors 24 hours per day. The remainder of the protocol involved an A-B-A work schedule design, whereby subjects worked straight days (0800-1630) during the second week of the study, the 2-2-1 schedule during the third week, and returned to a straight

Table 1

Study Protocol

DAYS	LABEL	PROTOCOL
Week1	**Baseline**	**Adaptation to Vitalog Monitor**
1	B1	0800-0900
2	B2	0800-0900
3	B3	0800-0900
4	B4	0800-0900
5	B5	0800-0900
6	W1	
7	W2	
Week2	**DAYS1**	**Straight Day Shift**
8	T1	0800-1630
9	T2	0800-1630
10	T3	0800-1630
11	T4	0800-1630
12	CD1	0800-1630
13	W3	
14	W4	
Week 3	**2-2-1**	**2-2-1 Schedule**
15	A1	1600-2430
16	A2	1400-2230
17	D1	0800-1630
18	D2	0600-1430
19	N	2400-0830
20	W5	
21	W6	
Week4	**DAYS2**	**Straight Day Shift**
22	CD2	0800-1630
23	CD3	0800-1630
24	CD4	0800-1630
25	CD5	0800-1630
26	CD6	0800-1200

LEGEND

B=Baseline
T=Training
A=Afternoon Shift
N=Night Shift
W=Weekend
CD=Control Day
D=Day Shift

day schedule for the fourth week. A synthetic work environment was created by using the Multiple Task Performance Battery (MTPB). The protocol is represented in Table 1. (All times are based upon the 24-hour clock notation.)

To assess the effect of the schedule on performance, circadian rhythms, sleep/wake cycles, and subjective experiences of mood and sleepiness, a number of measures were collected during the study: 1) Performance on the MTPB; 2) physiological measures (core body temperature, heart rate, and activity level); 3) daily logs of sleep/wake times and sleep quality ratings; 4) neuroendocrine measures; and 5) mood and sleepiness scales. As previously noted, only the performance data are presented here. The methodology is described in more detail in the first report (Della Rocco & Cruz, 1995).

Subjects

Twenty male subjects were selected from two different age groups for this study. Ten subjects were between the ages of 30-35, with a mean age of 32.0 years. These subjects were termed the "Younger" group. The second group of 10 subjects was between the ages of 50-55, with a mean age of 52.4 years. These subjects comprised the "Older" group. The younger age range was selected to be representative of ATCSs after reaching full performance level, and the older age range was selected because ATCSs must stop controlling air traffic when they reach age 56. Subject selection was restricted to males in order to minimize cyclic variations that might have interacted with or masked circadian variations in female subjects. Subjects were screened on a number of selection criteria, including medical, intelligence test scores, and drug, alcohol, tobacco and caffeine use (Della Rocco & Cruz, 1995).

Human Subject Utilization Committee Reviews. The study protocol and subject consent forms were approved by the University of Oklahoma Institutional Review Board. In addition, the study protocol was reviewed and approved through the research review process of the FAA Office of Aviation Medicine.

Subject Demographics. Seventeen of the 20 male subjects were Caucasian. Two subjects, one in each age group, were African-Americans. One subject in the Younger group was American Indian. Fifteen subjects were married. Half of the subjects reported prior military experience, eight of whom were in the Older group. One subject held a Master's degree, eight subjects had completed a Bachelor's degree, and three subjects had completed an Associate's degree. Five additional subjects reported having attended college. The remaining subjects had completed high school, with the exception of one subject who reported attaining a GED. Eight subjects reported being employed at the time of their participation in the study. Three subjects from the Older group were retired. Six of the subjects reported previous employment in an aviation-related field. One subject in the Older group was a former air traffic controller with the Air Force.

Apparatus

Multiple Task Performance Battery. The CAMI MTPB was used to collect the measures of performance. The MTPB provided an established approach to an intrinsically-motivating synthetic work situation, requiring time-shared performance of several tasks under varying workload conditions. This is because time-sharing and variation in workload are essential features of the ATC work environment. The MTPB consisted of six tasks that could be presented singly or in any combination. The tasks were computerized to control all signal presentations.

MTPB Equipment. The MTPB was based on a Digital Equipment Corporation MicroVAX II central processing unit and five TEKTRONIX Model 4125 color graphics workstations. The subject response panels were custom designed to operate in conjunction with the TEKTRONIX keyboard for subject inputs. Response times on the input devices ranged from 100 micro-seconds for the push buttons, to 10 milliseconds for responses from the keyboard. The CRT's dimensions were 15" w x 11.5" h (19" on the diagonal), with a graphics resolution of 1280 x 1024 pixels.

MTPB Tasks. The MTPB tasks included monitoring tasks, a tracking task, and information processing tasks that involved mental arithmetic, complex visual discrimination, and problem solving. These tasks measured basic psychological or behavioral functions relevant to control of complex systems in general, and ATC and pilot tasks in particular. A brief description of each task follows.

1. **Red and green light monitoring.** These were static monitoring tasks. Five pairs of lights (one red and one green per pair) were graphically represented at each corner and in the center of the CRT. Corresponding red and green push buttons were located next to each light just outside the CRT, with the buttons for the center lights located below the CRT. In each pair, the upper light was red and the lower one was green. The normal state for the red lights was "off," and for the green lights was "on." A signal consisted of a change in the normal state of either light to on or off, respectively. Subjects were instructed to respond to the signal by pushing the button corresponding to the light that changed. A response returned the signal to the normal state. The light returned automatically to the normal state if no response was initiated within 15 seconds of signal onset. The performance measures for these two tasks were mean response latency and percentage of correct responses. Response time was recorded in hundredths of a second separately for the red and green lights.

2. **Meter monitoring.** This task was a dynamic monitoring task. Four graphic representations of meters, with full-scale values from -50 to +50, were presented in the upper quarter of the CRT. A signal was present on a meter if the needle on the meter deflected by an identifiable amount to either the right or the left of center. The needle was in a constant state of "random" background disturbance ("noise"). When no signal was present, the needle deviated unpredictably with an average position of zero. With a signal present, the average position of the needle was shifted. A row of four pairs of buttons was mounted above the CRT, corresponding to each meter. Subjects were asked to respond to a signal by pressing one of the corresponding buttons to indicate a right or left deflection of the needle. When a button for a given meter was depressed, the background noise was removed and the pointer stopped on its "true" average value, giving immediate feedback as to the accuracy of the response. The background noise then began again. The measures of performance were mean response latency for all signals and percentage of correct responses. Response time was recorded in hundredths of a second.

3. **Mental arithmetic.** This task was presented graphically on the CRT about 1/3 of the distance from the bottom of the display. Problems consisted of three two-digit numbers in the following form: "XX + YY - ZZ = ." The subject was instructed to enter the answer in reverse serial order through the "10 key" keypad on the keyboard. The response was displayed on the CRT and the subject could correct the answer before pressing the enter key using the backspace key. If the answer was correct, a blue box appeared next to the answer. If the response was incorrect, a yellow-orange box appeared. The performance measures were mean response time for all problems and percent correct. Response time was measured between the time the problem was presented and a press of the enter key.

4. **Target Identification.** This was a pattern recognition task requiring mental rotation. This task was graphically presented in a square box between the meters and the mental arithmetic on the CRT. Response buttons were located on the right side of a panel below the CRT. A standard histogram pattern of six bars of varying height was presented. Two comparison patterns, which may have been rotated 0, 90, 180, or 270 degrees, were subsequently presented in succession. The subjects were to decide if one, both, or neither of the comparison patterns matched the initial target, and then press the appropriate button. If the response was correct, a blue box appeared next to the task on the CRT. An incorrect response resulted in the presentation of a yellow-orange box. Performance measures were mean response latency for all problems and percentage of correct responses.

5. **Code Lock.** This self-paced task involved two parts: 1) following procedures to decode a five-letter sequence, and 2) utilizing short-term memory

Table 2

Schedule of Tasks by 15-Minute Segment

	Time Segment							
	1	2	3	4	5	6	7	8
TASK	0-15	15-30	30-45	45-60	60-75	75-90	90-105	105-120
Monitoring Lights	x	x	x	x	x	x	x	x
Monitoring Meters	x	x	x	x	x	x	x	x
Arithmetic		x	x					
Code Lock			x	x	x	x		
Target ID						x	x	

to recall the sequence from memory after a 15-second delay. A panel below the CRT was equipped with five push buttons labeled A through E. Lights indicating 1) that the task was active, 2) correct and incorrect button presses, and 3) when a sequence had been decoded correctly, appeared in the middle of the lower quarter of the CRT. Subjects were instructed to decode the series of five letters using a left-to-right search pattern. This resulted in a predictable number of errors if the subject maintained the requested search pattern. When a subject received an indication of an incorrect response, the decoded portion of the sequence had to be re-entered before proceeding with the left-to-right search pattern to find the next letter. A correctly-entered sequence was followed by a 15-second delay, after which subjects re-entered the correct sequence again from memory. Performance measures were mean response latency and percent correct for both the solution and the recall portions of the task.

6. **Critical Tracking.** The Critical Task Tester MK 10 (Systems Technology, Inc., Hawthorne, CA) consisted of a Commodore SX-64 computer, a custom ROM program module, a CRT display (mounted above the main CRT display of the MTPB), and a custom manual controller (Smith & Jex, 1986). Critical Tracking was not combined with the other five tasks within the battery, but rather, was presented before and after each 2-hour MTPB session. Each presentation of the Critical Tracking task involved five trials. During each trial, subjects attempted to stabilize an arrow in the center of the screen by using the custom controller. The arrow became increasingly unstable as the task progressed, until the subject was no longer able to control it, and it went out of bounds to the left or right. Lambda was a value of the instability in the system, which increased steadily as the task progressed. The median lambda score from the five trials represented the score for that session.

The above tasks, with the exception of Critical Tracking, were variously combined into a two-hour protocol. Critical Tracking was administered immediately before and after each MTPB session. The order of presentation of MTPB tasks across each two-hour session was constant throughout the study. Tasks were added or removed to vary the workload every 15 minutes, according to the schedule presented in Table 2.

Procedures

The MTPB Laboratory was designed with five workstations. Thus, four groups of five subjects completed the protocol between September 1992 and February 1993. Each group of five subjects was balanced for subjects from the Older and Younger age groups (i.e., one group consisted of two subjects from the Older group and three from the Younger group, while the next group consisted of three subjects from the Older group and two from the Younger group).

Subjects reported to the laboratory from Monday through Friday, but continued wearing the portable physiological monitor throughout the weekends. Start dates for each of the groups varied due to

various scheduling difficulties. Groups 1 and 3 began their protocols as scheduled on a Monday (Day 1). Group 2, however, did not begin until Wednesday (Day 3), and Group 4 started the study on a Tuesday (Day 2).

MTPB Measures

MTPB performance was assessed on three levels: 1) Composite scores combining performance on all tasks into one of three scores (total composite [TC], passive task composite [PC], and active task composite [AC]) for each two-hour session; 2) raw scores for each task; and 3) composite scores for passive tasks during each 15-minute interval (see Table 2) within each session.

Composite scores were computed using the procedure reported by Mertens, McKenzie, and Higgins (1983). Raw scores for each task measure were standardized, with a mean of 500 and standard deviation of 100 across each 15-minute interval of every session from Day CD1 through CD4. Response time measures were multiplied by -1, so that higher scores represented faster response times, and lower scores represented slower response times. Composite scores were derived by averaging the various measures recorded for each task, such that each task contributed equally to the composite score. Specifically then, three task composites were computed: 1) an AC score (average of arithmetic, target identification, and code lock composite scores), 2) a PC score (average of red and green warning lights, and probability meter composite scores), and 3) a TC score (average of both active and passive task composite scores).

Because this was the first time the computerized MTPB had been used extensively, periodic equipment failures were experienced in five of 120 sessions. In these cases, the session was restarted at the closest 15-minute interval to the time of the failure. Equipment failure on Session 1 of D2 for Group 2 (Day shift on Thursday of the 2-2-1 week) resulted in loss of the entire two hours of data. Performance during this session was estimated utilizing mean substitution computed from means for each task during day shifts, Session 1 on days CD1, D1, CD2, CD3, and CD4, which provided control for time of day and learning effects. This was done only after analysis of the impact of the estimate on the overall outcome of the MANOVA was determined to have no effect. To assess this, MANOVAs were conducted on the data 1) without Group 2, 2) without D2, 3) without Session 1, and 4) with estimates for Group 2 on D2 Session 1. Each MANOVA revealed the same pattern of significance for main effects and interactions on composite scores. Therefore, scores were estimated.

Critical Tracking data were analyzed separately. The median lambda score (as a measure of a subject's control of the instability in the task) from the five trials per session was used as the score for each session.

Protocol. On the start date of the four-week protocol, subjects reported to the laboratory from 0800 to 1200 for orientation and training on use of the Vitalog physiological monitoring equipment. For the remainder of the first week, subjects reported to the laboratory for approximately one hour at 0800 each day. Researchers met with each subject individually to assess any reported problems, verify completion of logbooks, and download physiological data to a computer from the Vitalog monitors.

During the second week, subjects began a three-week period of working 8.5 hour days at the laboratory, Monday through Friday. Week 2 consisted of straight day shifts from 0800-1630. Subjects began training on the MTPB on the first day of the second week. By the second day of that week, a daily protocol was established. Table 3 presents a sample daily protocol for the day shift. The procedures were the same during the 2-2-1 schedule.

During the third week of the protocol, the subjects worked a 2-2-1 shift (Melton, 1982). The daily protocol detailed in Table 3 was followed during all shifts. The 2-2-1 was scheduled as shown in Table 4.

Subjects returned to working straight day shifts (0800-1630) during the fourth and final week of the protocol. Only two MTPB sessions were completed on the final day of the study, and the remaining time was used for collecting equipment and debriefing.

Table 3

Sample Daily Experimental Protocol

Time	Activity
0800-0830	Arrive at the laboratory and download physiological data
0830-0835	Tracking and Questionnaires
0835-1035	MTPB Session 1
1035-1045	Tracking and Questionnaires
1045-1130	Meal Break
1130-1135	Tracking and Questionnaires
1135-1335	MTPB Session 2
1335-1345	Tracking and Questionnaires
1345-1405	Break
1405-1410	Tracking and Questionnaires
1410-1610	MTPB Session 3
1610-1615	Tracking and Questionnaires
1615-1630	Debriefing, supplies

Table 4

The Study 2-2-1 Shift Schedule

Day	2-2-1	Hours Between Shifts
1	1600-2430	13.5
2	1400-2230	9.5
3	0800-1630	13.5
4	0600-1430	9.5
5	0000-0830	

Design and Data Analyses

The study was a mixed-model design with one between-subjects factor and two repeated-measures factors. The between-subjects factor was Age Group. The within-subjects factors were Day of the study and Session (or Sample in the case of neuroendocrine measures). Analyses and factorial models were specific to each dependent measure. Data analyses were conducted utilizing the SPSS statistical package, version 4.1 for VAX/VMS. For the majority of the analyses, the SPSS MANOVA procedure for repeated measures was employed.

Multiple comparisons were conducted utilizing procedures prescribed by Toothaker (1991) when significant interactions or main effects resulted from the MANOVA. The multiple comparison procedure (MCP) involved a series of paired t-tests on planned comparisons. The comparisons were developed as a result of application of chronobiological principles to the 2-2-1 work schedule. The control for probability of Type I error was established by referring the t-value to a Dunn critical value with parameters df = J(n-1) and C = K(K-1)/2, where J equals the number of between-subject groups, n equals the number of subjects per group, and K equals the number of repeated measurements for computation of all pairwise comparisons. If fewer than all possible pairwise comparisons were computed, then C equaled the number of planned comparisons (Toothaker, 1991). Each analysis of a dependent measure utilized a slightly different factorial design, based upon when measures were collected and the specific hypotheses tested, as follows.

The MTPB performance data were analyzed using a 2 (Age Group) x 10 (Day) x 3 (Session) mixed-model design. Age group represented the between-subjects factor. Both Day and Session were repeated measures factors. The 10 study days included in the analyses were a) the final day of the first week of day shifts, control day 1 (CD1), b) the five work days of the 2-2-1 shift week, including Afternoon 1 (A1), Afternoon 2 (A2), Day 1 (D1), Day 2 (D2), and the Night shift (N), and c) the first four days of the final week of the study, which served as control days 2-5 (CD2, CD3, CD4, and CD5). The first four days of DAYS1 week were dedicated to training and practice, and were not used in this analysis. Therefore, the first day considered a day shift control or baseline, CD1, was the last day of DAYS1. The last day of the protocol during DAYS2 was excluded from the analyses to avoid any end-of-study effect.

To simplify the MTPB multiple comparison analyses and reduce the probability of a Type I error, the following pre-planned comparisons were developed to focus specifically on the effects of the 2-2-1 shift quick-turn-arounds, anticipated Night shift performance decrements, and possible recovery period:

1) The first quick-turn-around: Performance on A2 (second afternoon shift of the 2-2-1) was compared to performance on D1 (first day shift of the 2-2-1).

2) The second quick-turn-around: Performance on D2 (second day shift of the 2-2-1) was compared to performance on N (the night shift). This transition was the second quick-turn-around during the week and was predicted to result in the worst performance on N of any shift during the week.

3) Performance on Session 1 of the Night shift was compared to Sessions 2 and 3 of the same shift.

4) Performance on Control Day 2 (CD2), the first day of the final week of straight day shifts, was compared to performance on D2, the second day shift of the 2-2-1. This comparison was designed to assess the possibility of continuing performance decrement following the 2-2-1 that may have persisted into the final week of day shifts.

The described pre-planned analyses resulted in 11 comparisons with 18 degrees of freedom when comparing Age x Session or Day x Session interactions and 3 planned comparisons with 18 degrees of freedom for multiple comparisons on main effects of Days or Sessions. The uninterpolated Dunn's critical values used for each of these cases were 3.48 and 2.69 ($\underline{p}<.05$) for two-way interaction and main effect comparisons, respectively (Toothaker, 1991, p. 145).

Workload data were examined for each of the six 15-minute intervals among Sessions of the Night shift utilizing a 2 (Age) x 3 (Session) x 6 (Interval) repeated measures model for the Passive and Active Composite Scores. Planned comparisons for Session x Interval interactions resulted in a total of 16 with 18 degrees of freedom. The uninterpolated Dunn's critical value was 3.62 (p<.05).

Critical tracking data analyzed for this paper investigated the changes in performance between the first session of the day and the last. This resulted in a 2 (Age Group) x 10 (Day) x 2 (Session) mixed model where age represented the between-subjects factor, and Day and Pre-Post work session assessments represented the repeated measures factors. Planned comparisons included: 1) Daily Pre-Post assessments from CD1, through the 2-2-1, to CD2; 2) CD1, day shift, Pre-workday assessments to each day of the 2-2-1 as well as to CD2 Pre-workday assessments; and 3) CD1 Post-workday assessments to each day of the 2-2-1 as well as to CD2 Post-workday assessments. This resulted in a total of 19 planned comparisons with 18 df. An uninterpolated Dunn's critical value of 3.62 for 20 comparisons and 15 df was used.

RESULTS

MTPB performance data were analyzed on three levels to investigate changes due to the shift work schedules in this study: 1) *MTPB composite scores,* standardized for each task for each two-hour session and combined into three composites for *Total* (all tasks), *Passive* (green warning lights, red warning lights, probability meters) and *Active* tasks (arithmetic, target identification, code lock), 2) *Individual MTPB task raw scores,* and 3) *15-minute intervals* for secondary (passive) tasks as a method for examining the effects of workload. All results tables and figures can be found in Appendices A and B, respectively.

MTPB Composite Scores

This section presents the results of analyses of the MTPB composite scores. Three composite scores were computed from the standardized task scores. The Total Composite Score included all six tasks. The Active Composite Score included the active tasks (Arithmetic, Target ID, and Code Lock). The Passive Composite Score included the passive tasks (Red Warning Lights, Green Warning Lights, and Probability Meters). Higher composite scores indicate better performance.

Total Composite Scores. Figure 1 and Table 5 present descriptive statistics for the Total Composite Scores. Table 6 presents the MANOVA summary table for Total Composite Scores.

The results of the 2 x 10 x 3 MANOVA revealed significant interactions for 1) Age by Day, $F(9, 162) = 4.15$, $p<.01$, and 2) Day by Session, $F(18, 324) = 2.76$, $p<.01$, as well as a significant main effect for Day of the study, $F(9, 162) = 4.60$, $p<.01$. There was no significant main effect of Age Group. Multiple comparisons, computed per the planned comparisons for Total Composite Scores, revealed no significant differences between Days, Sessions or Age that resulted from the 2-2-1 shift schedule.

Post hoc comparisons on Day revealed evidence that learning occurred well into the 2-2-1 shift work week. The performance mean of 486 for CD1 was significantly lower than the mean of 502 for day A2, $t(19) = 4.15$, $p<.05$, and the mean of 507 for day A3, $t(19) = -3.95$, $p<.05$. The mean for day A1 ($M = 494$) was significantly lower than the mean for day D1 ($M = 507$), $t(19) = 3.93$, $p<.05$. These findings demonstrated that performance improved significantly into the middle of the 2-2-1 schedule, through approximately 46 hours of practice. These comparisons were computed for the Total Composite scores to demonstrate the degree to which learning continued into the 2-2-1 week. Further post hoc analyses for learning effects on the other MTPB measures were not computed here, because they were beyond the scope of this report.

Of final note, although not within the planned comparisons of the effects of the 2-2-1, a decline in the Total Composite Scores of the Younger group can be observed in Figure 1 (and Table 5) for Session 2 of CD4. This was due to one Younger subject falling asleep for 10 minutes during Interval 6.

Passive Composite Scores. Figure 2 and Table 7 present descriptive statistics for the Passive Composite Scores. Table 8 presents the MANOVA summary table for the Passive Composite Scores.

Results of the 2 x 10 x 3 MANOVA for Passive Composite Scores revealed significant interactions for Age by Day, $F(9, 162) = 3.45$, $p<.001$, and Day by Session, $F(18, 324) = 2.03$, $p<.05$. Planned multiple comparisons on the Age by Day interaction failed to attain significance. However, planned multiple comparisons on the Day by Session interaction revealed that performance on the passive tasks declined significantly over the course of the Night shift. Paired t-tests among the sessions of the Night shift revealed that the Passive Composite Scores for Session 2 ($M = 493$), $t(18) = 3.82$, $p<.05$, and Session 3 ($M = 479$), $t(18) = 3.75$, $p<.05$, were significantly lower than scores during Session 1 ($M = 510$). No significant differences were found between the sessions on the day before and the day after the quick-turn-arounds, A2-D1 and D2-N, respectively, or on the comparison of D2 to CD2.

Active Composite Scores. Figure 3 and Table 9 present descriptive statistics for the Active Composite Scores. Table 10 presents the MANOVA summary table for the Active Composite Scores.

Results of the 2 x 10 x 3 MANOVA for Active Composite Scores revealed a significant interaction for Age by Day, $F(9, 162) = 3.04$, $p<.05$, and for Day by Session, $F(18, 324) = 2.33$, $p<.05$, and a main effect for Day of the study, $F(9, 162) = 6.50$, $p<.001$. Planned multiple comparisons for the Age by Day interaction failed to reach statistical significance. Planned paired t-tests comparing the Day by Session interaction revealed no significant differences between sessions on A2 and D1 on the first quick-turn-around, or between D2 and N Sessions 1 and 2, or between D2 and CD2. Active Composite Scores were significantly lower, however, on N Session 3 ($M = 464$) than D2 Session 3 ($M = 505$), $t(18) = 3.51$, $p<.05$. Multiple comparisons for the main effect of Day revealed that performance on the Night shift ($M = 480$) was significantly lower than performance on D2, the prior Day shift ($M = 506$), $t(18) = 3.17$, $p<.05$.

MTPB Individual Tasks

This section presents the data analyses of performance of each of the six individual tasks in the MTPB: Arithmetic, Code Lock, Target Identification, Probability Meters, Red Warning Lights, and Green Warning Lights. For each task, measures of accuracy (Percent Correct) and speed (Response Time) were reported here. Code Lock was composed of two parts: Solution and Recall. Data for accuracy and speed were reported for each part separately.

Arithmetic. Figure 4 and Table 11 present descriptive statistics for Arithmetic Percent Correct. Table 12 presents the MANOVA summary table for Arithmetic Percent Correct.

Results of the 2 x 10 x 3 MANOVA for Arithmetic Percent Correct revealed a significant interaction for Age by Day, $F(9, 162)=2.01$, $p<.05$, and significant main effects for Day, $F(9, 162)=6.25$, $p<.001$, and Session, $F(2, 36)= 7.39$, $p<.05$. Planned multiple comparisons for the Age by Day interaction and main effect of Day failed to reach statistical significance. The comparisons for main effect of Session revealed that Arithmetic Percent Correct improved significantly between Session 1 ($M=95.1$) and Session 3 ($M=96.1$), $t(18) = 3.47$, $p<.05$.

Figure 5 and Table 13 present descriptive data for Arithmetic Response Time. Table 14 presents the MANOVA summary table for Arithmetic Response Time.

Results of the 2 x 10 x 3 MANOVA for Arithmetic Response Time revealed a significant interaction for Age by Day of the study, $F(9, 162) = 4.07$, $p<.001$, as well as significant main effects for Day, $F(9, 162) = 3.27$, $p<.001$, and Session, $F(2, 36) = 12.86$, $p<.001$. Planned comparisons on the interaction of Age by Day, as well as the main effect for Day failed to reach statistical significance. However, as with Arithmetic Percent Correct, performance improved after the first Session. Response Times were significantly faster during Session 2 ($M = 8.2$ seconds), $t(18) = 4.40$, $p<.05$, and Session 3 ($M = 8.2$ seconds), $t(18) = 3.61$, $p<.05$) than during Session 1 ($M = 8.4$ seconds) .

Code Lock. The Code Lock Task involved two parts, solution and recall. Percent correct and response times are presented for each of these parts

separately. Figure 6 and Table 15 present descriptive statistics for Code Lock Solution Percent Correct. Table 16 presents the MANOVA summary table for Code Lock Solution Percent Correct.

Results of the 2 x 10 x 3 MANOVA for Code Lock Solution Percent Correct revealed a significant three-way interaction for Age by Day by Session, $F(18, 324) = 1.88$, $p<.05$. Two-way interactions were found to be significant for Age by Day, $F(9, 162) = 2.02$, $p<.05$, and Day by Session, $F(18, 324) = 2.87$, $p<.001$. None of the planned comparisons for the Age by Day or the Day by Session interactions were found to be significant.

Figure 7 and Table 17 present descriptive statistics for Code Lock Solution Response Time. Table 18 presents the MANOVA summary table for Code Lock Solution Response Time.

Results of the 2 x 10 x 3 MANOVA for Code Lock Solution Response Time revealed a significant Day by Session interaction, $F(18, 324) = 2.06$, $p<.05$, as well as a significant main effect for Day, $F(9, 162) = 8.05$, $p<.001$, and Session, $F(2, 36) = 5.76$, $p<.05$. Planned multiple comparisons for the Day by Session interaction revealed that solution time was significantly slower on N Session 3 (M = 16.1 seconds) than on D2 Session 3 (M = 13.8 seconds), $t(18) = 3.97$, $p<.05$. Planned comparisons for differences between Days revealed that Code Lock Solution Time was significantly slower on the Night shift (M = 15.3 seconds) than on the prior Day (D2) shift (M = 14.1 seconds), $t(18) = 3.12$, $p<.05$. Code Lock Solution Time was found to improve over Sessions, such that subjects solved the Code Lock problem significantly faster during Session 3 (M = 14.1 seconds) than Session 1 (M = 14.9 seconds), $t(18) = 3.07$, $p<.05$ over the course of the study.

Figure 8 and Table 19 present descriptive statistics for Code Lock Recall Percent Correct. Table 20 presents the MANOVA summary table for Code Lock Recall Percent Correct.

Results of the 2 x 10 x 3 MANOVA for Code Lock Recall Percent Correct revealed a significant Age by Day interaction, $F(9, 162) = 3.97$, $p<.001$, as well as a significant main effect for Day of the study, $F(9, 162) = 3.62$, $p<.001$. Multiple comparisons for the Age by Day interaction revealed a significant difference between Age groups on D1, after the first quick-turn-around, $t(18) = 3.93$, $p<.05$. The mean percent correct for the Older group, 95.26, was greater than one standard deviation below the mean for the Younger group, 97.38. The decline in Code Lock Recall Percent Correct from 95.87 on D2 to 93.92 on N was also found to be significant, $t(18) = 3.16$, $p<.05$.

Figure 9 and Table 21 present descriptive statistics for Code Lock Recall Response Time. Table 22 presents the MANOVA summary table for Code Lock Recall Response Time.

Results of the MANOVA on Code Lock Recall Response Time revealed a significant Age by Day interaction, $F(9, 162) = 2.91$, $p<.05$, and a significant Day effect, $F(9, 162) = 2.92$, $p<.05$. Planned comparisons for the Age x Day interaction revealed no significant differences between Age groups. Multiple comparisons for the Day main effect revealed that mean Code Lock Recall Response Time was significantly slower on the Night shift (M = 5.85 seconds) compared to the previous Day (D2) shift (M = 5.0 seconds) by nearly 1 second, $t(18) = 2.85$, $p<.05$.

Target Identification. Figure 10 and Table 23 present descriptive statistics for Target Identification Percent Correct. Table 24 presents the MANOVA summary table for Target Identification Percent Correct.

Results of the 2 x 10 x 3 MANOVA for Target Identification Percent Correct revealed significant main effects for Day, $F(9, 153) = 4.42$, $p<.001$, as well as Session, $F(2, 34) = 6.20$, $p<.05$. Planned multiple comparisons for Day of the study revealed that accuracy was lower on the Night shift (M = 85.76) than the previous Day shift (M = 90.31), $t(18) = 3.71$, $p<.05$. Results of planned comparisons on the main effect of Session revealed that performance on Sessions 2 (M = 89.12), $t(18) = 2.80$, $p<.05$, and 3 (M = 89.13), $t(18) = 2.99$, $p<.05$ was significantly lower than on Session 1 (M = 90.52).

Figure 11 and Table 25 presents descriptive statistics for Target Identification Response Time. Table 26 presents the MANOVA summary table for Target Identification Response Time.

Results of the 2 x 10 x 3 MANOVA revealed a significant three-way interaction for Age by Day by Session, $F(18, 306) = 1.80$, $p<.05$, and a significant two-way interaction for Day by Session, $F(18, 306) = 2.50$, $p<.001$. In addition, significant main effects were found for Day, $F(9, 153) = 2.54$, $p<.05$, and Session, $F(2, 34) = 6.14$, $p<.05$. Planned multiple comparisons for the Day by Session interaction revealed a significant slowing of the Response Time for Target Identification during Session 3 of the Night shift (M = 2.7 seconds) compared to Session 3 of the previous Day shift, D2, (M = 2.2 seconds), $t(18) = 3.84$, $p<.05$. Planned comparisons on the Day main effect revealed no significant differences. Comparisons for the Session main effect revealed that Target Identification Response Time was significantly slower during Session 2 (M = 2.2 seconds) than during Session 1 (M = 2.1 seconds), $t(18) = 2.75$, $p<.05$, across the duration of the study.

Probability Meters. Figure 12 and Table 27 presents descriptive statistics for Probability Meters Percent Correct. Table 28 presents the MANOVA summary table for Probability Meters Percent Correct.

The results of the 2 x 10 x 3 MANOVA for Probability Meters Percent Correct revealed only a significant Day by Session interaction, $F(18, 324) = 1.90$, $p<.05$. Multiple comparisons for the Day by Session interaction revealed no significant differences on Probability Meter monitoring accuracy measures comparing Sessions on the days before and after both quick-turn-around shift changes or the first day shift after the 2-2-1.

Figure 13 and Table 29 present descriptive statistics for Probability Meters Response Time. Table 30 presents the MANOVA summary table for Probability Meters Response Time.

Results of the 2 x 10 x 3 MANOVA revealed significant two-way interactions for Age by Day, $F(9, 162) = 2.65$, $p<.05$, as well as Day by Session, $F(18, 324) = 2.71$, $p<.001$. Planned multiple comparisons for the Age x Day and the Day x Session interactions revealed no significant differences for Probability Meter Response Times for the quick-turn-around shifts or the first Day shift after the 2-2-1.

Red Warning Lights. Figure 14 and Table 31 present descriptive statistics for Red Warning Lights Percent Correct by Age group, Day of the study, and Session. Table 32 presents the MANOVA summary table for Red Warning Lights Percent Correct. No significant differences in performance were found on this task due to Age, Day, or Session. Performance on this task was maintained at nearly 100% accuracy for the duration of the study.

Figure 15 and Table 33 present descriptive statistics for Red Warning Lights Response Time. Table 34 presents the MANOVA summary table for Red Warning Lights Response Time.

Results of the 2 x 10 x 3 MANOVA for Red Warning Lights Response Time revealed that, although there was no significant performance decrement in Percent of Correct responses on this task, there were significant decrements on the Response Times. Analyses resulted in a significant Age by Day interaction, $F(9, 162) = 2.66$, $p<.05$, and a significant main effect for Session, $F(2, 36) = 6.83$, $p<.05$. Planned multiple comparisons failed to reach statistical significance for the Age by Day interaction; however, for the Session main effect, Response Times to Red Warning Lights were significantly faster during Session 1 (M=1.73 seconds) than either Session 2 (M=1.87 seconds), $t(18) = 3.13$, $p<.05$, or Session 3 (M=1.83 seconds), $t(18) = 2.65$, $p<.05$.

Green Warning Lights. Figure 16 and Table 35 present descriptive statistics for Green Warning Lights Percent Correct.Table 36 presents the MANOVA summary table for Green Warning Lights Percent Correct. Results revealed that, as with the Red Warning Lights, there was no significant performance decrement on accuracy of responding to the Green Warning Lights.

Figure 17 and Table 37 present descriptive statistics for Green Warning Lights Response Time. Table 38 presents the MANOVA summary table for Green Warning Lights Response Times.

Results of the MANOVA for response times on the Green Warning Lights revealed a significant interaction for Age by Day, $F(9, 162) = 3.43$, $p<.001$, as well as a main effect for Day, $F(9, 162) = 4.48$, $p<.001$. Planned comparisons failed to reach statistical significance for the Age by Day interaction or the Day main effect.

Workload

This section presents the descriptive statistics for the Passive Composite and Active Composite Scores by Session and by 15-minute interval for the Night shift. It should be noted that workload varied from Interval 1 to Interval 8 in terms of the number of active tasks being presented along with the passive tasks. During Intervals 1 and 8, only the passive tasks were presented (low workload). Active tasks were only present during Intervals 2 through 7. Intervals 2, 4, 5, and 7 represented medium workload conditions in which one active task was presented along with the passive tasks. Finally, intervals 3 and 6 represented high workload conditions in which two active tasks were presented along with the passive tasks.

Figure 18 and Table 39 present descriptive statistics for the Passive Composite Scores during the Night shift. Table 40 presents the MANOVA summary table for Passive Composite Scores by 15-minute interval during the Night shift.

Results of the 2 x 3 x 8 MANOVA for the Passive Composite Scores on the Night shift revealed a significant three-way interaction of Age by Interval by Session, $F(14, 252) = 2.02$, $p<.05$, a two-way interaction for Interval by Session, $F(14, 252) = 5.41$, $p<.001$, as well as a significant main effect for Interval, $F(7, 126) = 9.08$, $p<.001$. Planned comparisons to examine the Session by Interval interaction investigated performance changes within each interval across each Session. Results revealed: 1) Interval 2 (medium workload) for Session 3 ($M = 490$) was significantly lower than for Session 1 ($M = 524$), $t(18) = 4.48$, $p<.05$, representing a 6% decline in performance; and 2) Interval 5 (medium workload) for Session 2 ($M = 479$) was significantly lower than Session 1 ($M = 523$), $t(18) = 5.05$, $p<.05$, representing an 8% decline.

Figure 19 and Table 41 presents the descriptive statistics for the Active Composite Scores by Session and Interval during the Night shift. Table 42 presents the MANOVA summary table of Active Composite Scores by Interval during the Night shift.

Results of the 2 x 3 x 6 MANOVA for the Active Composite Scores on the Night shift revealed a significant interaction of Interval by Session $F(10,180)=2.66$, $p<.05$, a main effect for Interval $F(5,90)=6.97$, $p<.001$, as well as a significant main effect for Session $F(2,36)=6.98$, $p< .001$. Examination of the planned comparisons revealed no significant differences between Sessions, suggesting that subjects protected their performance on the Active Tasks, but failed to maintain a similar level of performance for the Passive Tasks.

Critical Tracking

Figure 20 and Table 43 present the descriptive statistics for the median lambda scores for the Critical Tracking Task from days CD1 through CD5 for the pre-MTPB Session 1 and the post-MTPB Session 3. Higher scores indicate better performance. Table 44 presents the MANOVA summary table for Critical Tracking.

The results of the 2 x 10 x 2 MANOVA revealed a significant three-way interaction of Age by Day by Session, $F(9, 162)=3.08$, $p<.05$, a significant two-way interaction of Day by Session, $F(9,162)=2.91$, $p<.05$, and a significant main effect for Day, $F(9, 162)=17.7$, $p<.001$. There was no significant main effect of Age Group. Planned multiple comparisons to assess the Day by Session interaction revealed that:

1) Performance was significantly better, compared to the pre tracking session on CD1 ($M=3.98$), for the pre tracking session on D2 ($M=4.42$), $t(18)=3.74$, $p<.05$; N ($M=4.48$), $t(18)=4.02$, $p<.05$; CD2 ($M=4.48$), $t(18)=4.03$, $p<.05$; and CD3 ($M=4.56$), $t(18)=4.13$, $p<.05$.

2) Post tracking performance on CD3 ($M=4.68$) was significantly better than on CD1 ($M=4.20$), $t(18)=4.84$, $p<.05$.

Planned multiple comparisons to assess the main effect for Day did not reach statistical significance. The Age by Day by Session interaction was most evident on the recovery from the Night shift to

CD2. Up until CD2, the Older and Younger group's performance had been quite comparable for the pre and post tracking sessions. On CD2, however, this pattern did not hold true on the post tracking session where the older group outperformed not only the younger group but their own performance on the pre tracking session. There was, however, strong continuous learning evidenced in this measure that continued throughout the duration of the study.

DISCUSSION

This report presented the performance data from a laboratory-based investigation of a unique, rapidly-rotating shift schedule, the 2-2-1, commonly used by Air Traffic Control Specialists. While a series of previous field studies on ATCSs had included investigation of the 2-2-1 schedule, none had involved controlled laboratory-based research, nor had any included performance measures. Because air traffic control is a safety-related occupation, it was important to investigate the extent to which the 2-2-1 schedule could result in possible adverse effects, such as performance decrements.

Subjects participated in a four-week study in which the first week was a baseline, followed by a three week, A-B-A designed work week schedule, comparing straight day schedule (A condition) performance to performance on the 2-2-1 schedule (the B condition). The A-B-A design, in combination with instructions to subjects to maintain stable sleep/activity patterns, was structured to ensure, as nearly as possible, that subjects were day-oriented in their circadian rhythms prior to the 2-2-1, and then to assess any disruption and recovery due to the 2-2-1.

The study addressed the issue of whether or not the subjects working the 2-2-1 were able to maintain a relatively stable day orientation, or whether the phase-advancing properties of the schedule would be so disruptive as to manifest in subject performance. Four specific hypotheses were investigated to determine the extent to which the 2-2-1 schedule: 1) disrupted sleep patterns and resulted in cumulative partial sleep loss; 2) resulted in performance decrements on a complex cognitive task in the synthetic work environment; 3) interacted with age to cause greater adverse effects in older subjects; and 4) caused changes in measures that continued into the day shift week following the 2-2-1 and required a recovery period.

The present study introduced a new, computerized version of the MTPB. The MTPB had historically provided a motivating synthetic work environment over extended periods of time for purposes of investigating air crew staffing schedules (Chiles et al., 1968) and had been validated as a predictor of success in ATCS training (Chiles & West, 1974). With the exception of a substantial learning curve, subjects maintained relatively stable performance over the required three-week protocol in this study.

One important contribution of the present study resided in the outcome of the performance data under the 2-2-1 schedule. The analyses focused primarily on the two quick-turn-arounds in the 2-2-1, a possible recovery period, and the specific performance on the Night shift, with the hypotheses that each of these characteristics of the schedule would lead to performance decrements. The effect of the 2-2-1 on complex task performance was investigated on three levels: 1) Composite scores for Total, Passive and Active tasks for each 2-hour session, 2) each individual task measure, and 3) 15-minute Workload changes during the Night shift.

The results from analyses of the composite scores revealed that the only significant decrement in performance occurred on the Night shift. Significant decrements were found in both Active and Passive Composite scores during the third session of the Night shift. Thus, the hypothesis that both quick-turn-arounds within the 2-2-1 would result in performance decrements was only partially supported.

The composite scores, however, combined speed and accuracy measures. Thus, even though response times were converted such that higher scores indicated faster performance, opposing changes in speed or accuracy due to time of day or fatigue effects could have been masked or minimized by the

analyses of the combined scores. Therefore, the effects of the 2-2-1 schedule on performance on each individual task measure of speed and accuracy were presented.

Examination of performance on each measure of individual tasks revealed a similar pattern of performance decrements with the turn-around to the Night shift. Significant differences were found, however, in the Active tasks, exclusively. While Arithmetic performance revealed no significant differences due to the shift, both Code Lock and Target Identification did. Code Lock consisted of two separate parts: the procedural task of systematically decoding the series of five letters, and subsequent recall 30 seconds later utilizing short-term memory. Accuracy of decoding the letter sequence in the procedural part remained intact throughout the 2-2-1 schedule, although response times were slowed on the Night shift, particularly during the third session. Code Lock Recall was the only task to reveal a hint that age, as well as the first quick-turn-around in the 2-2-1, might result in performance decrements. The Older group demonstrated decrements in accuracy of Recall on both quick-turn-around days. The Younger group demonstrated a decrement in Recall on the Night shift. Response time was slowed for both the Older and Younger groups on the Night shift. Finally, Target Identification demonstrated decrements in both speed and accuracy on the Night shift. No significant decrements were observed in any individual measure on the passive tasks.

The hypothesis that the two quick-turn-arounds would result in performance deficits was only partially substantiated. There was some evidence, however, in Code Lock Recall that the quick-turn-arounds may have differentially affected the Older group. Performance on the first two days of the final Day shift week following the 2-2-1 indicated that performance did not require a period of recovery. It should be noted that subjects did complain about feeling shift-lagged on the first day of the final week, but the feelings were not reflected in performance.

Performance decrements during the Night shift for each workload level were investigated through assessment of the effect on secondary (passive) tasks under changes in workload by addition of Active tasks. Results revealed a significant three-way interaction of Age x Interval x Session in which the Older group's scores were generally lower than the Younger group's scores during most intervals in Session 3, and declined over Session 2 to their lowest levels during a high workload condition (Interval 6) that combined the passive tasks with both Code Lock and Target Identification. Interval scores generally declined with increased workload. Significant performance decrements occurred, however, during two moderate workloads. Specifically, performance on the Passive tasks during Session 3 Interval 2 (when Arithmetic was also present) was significantly lower by approximately 12% than Session 1 Interval 2. In addition, performance decrements of approximately 8% were found for the Passive tasks in Interval 5, when Code Lock was also present, between Session 1 and 2. Examination of performance on the Active Tasks by 15-minute intervals revealed no significant decrements, suggesting that subjects protected performance on the Active Tasks.

Because of the observed impact on the sleep/wake cycle over the course of the schedule (Della Rocco & Cruz, 1995), it was not surprising to find that the largest decrement in performance was observed on the last shift, a night shift. It was notable, however, that performance during the first 2-hour MTPB session of the shift was not significantly worse than performance on the previous day shift. Performance declined over the course of the Night shift. Such a pattern would have been predicted by the chronobiology if subjects were successful at maintaining a day-orientation with their circadian rhythms. It also suggests that interventions to improve employee alertness may not be needed during the first few hours of the night shift, but become critical during the final two-thirds of the shift.

There was a substantial learning curve for MTPB performance. Based upon several traditional assessments of asymptotic performance, including the assessment of differential stability (recommended by Damos [1989]), we had reported that subjects attained asymptotic performance by the end of the first week after 28 hours of practice (Cruz, Della Rocco, & MacLin, 1993). Assessment of stabiliza-

tion was based on analysis of the composite scores. Based upon these initial analyses, CD1, the last day of the MTPB training week, was originally selected as a day shift baseline day, ideally for comparison to the effects of the 2-2-1. Performance, however, continued to improve well into the 2-2-1 week (through Wednesday). The Older subjects appeared to learn more slowly, but attained the same level of performance as the Younger group by the end of Wednesday (D1). The subjects had completed 46 hours of working on the full battery by this day. Examination of the full 86 hours of MTPB performance data during the present protocol revealed that better stabilization probably occurred in the present study closer to the 48 hours of practice reported by Chiles, et al. (1968). Although learning curves were not within the scope of the present report, significant differences existed between performance on Wednesday (D1) of the 2-2-1 week and Thursday of the final week (CD4), indicating that performance continued improvement throughout the three weeks of the study. The subjects, themselves, presaged this finding in post-study debriefings, in which they described modifications to their time-sharing strategies that continued through the middle of the 2-2-1 week. As with studies on other computerized batteries (Damos, 1989), this finding was not entirely unexpected; however, it did substantially complicate the data analyses. It would suggest that for future studies utilizing a similar MTPB 2-hour task schedule, a minimum of 48 hours practice be provided prior to experimental interventions.

The results of the present study suggest that the problems a counterclockwise, rapidly-rotating shift schedule poses for complex task performance may be localized to the night shift, and that such problems could be addressed directly through fatigue and sleepiness countermeasures. The detrimental effects of the schedule on performance were not evident in this study until the Night shift, even though the sleep/wake cycle data demonstrated significant disruption. The finding of a performance decline on the Night shift was predicted by the chronobiology, and was, therefore, not surprising. A basis for the performance effects on the night shift was further established as the 2-2-1 progressed with the phase advances and sleep loss patterns. The night shift followed 1) three phase advances, 2) an average period of 3.7 hours of sleep (Della Rocco & Cruz, 1995), and 3) testing that occurred during the circadian troughs of day-oriented individuals.

Damos (1989) reviewed studies on the circadian rhythm variability in performance of selected information processing tasks. Her review, after substantial cautions about methodological problems, indicated that the range of differences between mean performance and either the maximum or minimum performance due to circadian effects were less than 10%. Similar findings of performance decrements of approximately 8% were found in the phase-shift studies on the MTPB reported by Higgins et al. (1975, 1976). In these studies, performance decrements were evident after sleep restriction to 3 hours in their protocol and during testing between 2400-0800, as they phase-shifted their subjects. The majority of findings from MTPB performance in the present study ranged between 0-12% decrements on the Night shift during the 2-2-1, with the exception of response time on Target Identification (a 23% decrement). As such, it remains unclear whether the performance decrements were due primarily to the sleep loss just prior to the Night shift, or whether the decrements might be due solely to the effects of circadian variation. Because the observed decrement was within the range of previously reported effects of either sleep loss or circadian rhythm variability, it did not appear that an adverse additive interaction resulted from the combination of sleep loss and time of day.

In her review of the circadian rhythm variability on individual tasks, Damos questioned the operational significance of such a decline that only varied by 10% from the mean. However, she suggested that effects may have been masked, due to methodological inadequacies of the studies reviewed. Monk (1990), while also noting methodological flaws in the historical data base, cautioned that circadian variation was a robust fluctuation, as well as the result of the confluence of a number of factors, including time-of-day, sleep disruption and loss, and disruption of social and domestic status. Higgins

et al. (1975) recommended restricting an individual's performance to something other than the performance of complex tasks after a sleep period as short as 3 hours until subjects achieved a normal night of sleep.

Previous CAMI field studies on the 2-2-1 revealed the schedule to be an improvement over the straight-5 rotation, but probably slightly more stressful than straight days (Melton, 1982). A recent field study compared a 10-hour schedule to variations of the 2-2-1 and found that working a schedule of four 10-hour shifts was not worse than the 2-2-1 (Schroeder, Rosa, & Witt, 1995). The present study compared the 2-2-1 to day shifts and added laboratory-based controls and performance measures to the knowledge base. Even though the 2-2-1 was found to substantially disrupt sleep patterns, performance decrements were apparent only on the night shift.

The findings in this study may be conservative in estimating the disruptive effects of the 2-2-1 schedule for the following reasons: 1) subjects only worked one 2-2-1 rotation, whereas, in the ATCS work force, working the schedule can be a chronic exposure for a number of years; 2) instructions to the subjects, as well as the study protocol, effectively required that subjects restrict their life styles to unusually stable patterns, although some activities, such as jogging and refereeing basketball games were allowed; and 3) subjects were matched on mental abilities, which would not necessarily be the case in the work force, especially in the older age range.

The present study failed to find as many age-related differences as were predicted from the literature review. This could possibly be attributed to the restriction in range, due to the strict subject screening criteria used. Subjects were selected based upon intelligence test data normed on newly hired ATCS students in the FAA Academy. The average age of the normative group was 25.2. Therefore, the failure to identify a greater number of differences in the age groups should not be generalized to the broader work force.

SUMMARY AND RECOMMENDATIONS

Findings presented from this study demonstrated that the 2-2-1 shift schedule utilized by ATC facilities substantially disrupted the sleep/wake cycle (Della Rocco & Cruz, 1995). The disruption took the form of a single phase delay of 2-hours, followed by three phase-advances of both asleep and awake times. The mean sleep duration was not significantly affected until the quick-turn-around before the night shift, when subjects were only able to sleep for an average of 3.7 hours. Consequences of the disruption were not substantially evident in the MTPB performance until the night shift. Performance was found to decline over the course of the night shift and was particularly manifest in the active task scores. Of particular note was the night shift decrement in speed and accuracy on Target Identification, a spatial perceptual task, measuring abilities required in ATC.

The study was conducted using non-ATC subjects in a laboratory environment; and therefore, the results may be conservative estimates of the effects of the 2-2-1. However, it was encouraging that: 1) the sleep patterns were similar to field studies with ATC personnel, and 2) that performance levels were maintained on the MTPB for the duration of the study. Thus, the results obtained from this study should have applicability to serve as a basic foundation for development of a research program on countermeasures and coping strategies. For any resolution of the discussion of the impact of the 2-2-1, the circadian, physiological, and additional data must be analyzed.

As a result of the findings in this study, three areas were suggested for examination as candidates for countermeasures. These included the development of direct interventions to improve alertness on the night shift (bright light exposure and/or napping), sleep management education for employees designed to coincide with the basic tenants of the 2-2-1 schedule design, and finally, schedule redesign to minimize the number of quick-turn-arounds.

The present study addressed only the acute effects of working one week of the 2-2-1 schedule. Future research should address the effects of working a quick-turn-around schedule on a chronic basis, as well as identification of individual differences in response to adaptation to the quick-turn-around schedules.

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APPENDIX A

TABLES

Table 5

Means and Standard Deviations for MTPB Total Composite Scores

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Total Composite											
Session 1											
Younger	Mean	488	504	518	514	514	504	509	509	505	514
	SD	36	28	27	32	36	43	34	43	45	41
Older	Mean	471	474	481	498	501	504	498	506	511	510
	SD	31	43	40	22	33	28	37	38	25	29
Session 1	**Mean**	**479**	**489**	**500**	**506**	**508**	**504**	**503**	**507**	**508**	**512**
	SD	**35**	**39**	**38**	**28**	**35**	**35**	**35**	**40**	**36**	**35**
Session 2											
Younger	Mean	500	508	511	516	491	495	498	502	471	508
	SD	30	29	31	36	64	55	48	62	113	40
Older	Mean	480	487	486	495	506	476	498	506	511	510
	SD	31	27	32	34	30	60	32	31	20	35
Session 2	**Mean**	**490**	**499**	**499**	**505**	**498**	**485**	**498**	**504**	**491**	**509**
	SD	**31**	**29**	**33**	**36**	**49**	**57**	**40**	**48**	**82**	**37**
Session 3											
Younger	Mean	496	514	521	519	503	484	502	505	501	509
	SD	32	26	27	38	61	60	46	59	38	40
Older	Mean	482	478	494	498	503	459	506	509	514	512
	SD	30	46	42	36	31	76	33	33	29	32
Session 3	**Mean**	**489**	**496**	**508**	**509**	**503**	**472**	**504**	**507**	**508**	**510**
	SD	**31**	**40**	**37**	**37**	**47**	**68**	**39**	**47**	**34**	**36**

Table 6

MANOVA Summary Table for MTPB Total Composite Scores

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	670614.83	37256.38	N.S.
Between Subjects	18	12115.37	12115.37	
Day of Study	9	36442.37	4049.15	4.60**
Age by Day	9	32867.15	3651.91	4.15**
Within Subjects	162	142542.03	879.89	
Session	2	1574.64	787.32	N.S.
Age by Session	2	1648.00	824.00	N.S.
Within Subjects	36	20209.80	561.38	
Day by Session	18	17553.38	975.19	2.76**
Age by Day by Session	18	7406.50	411.47	N.S.
Within Subjects	324	114622.09	353.77	

*p<.05

**p<.001

Table 7
Means and Standard Deviations for Passive Composite Scores

Study Day	CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Passive Composite										
Session 1										
Younger Mean	495	511	513	508	510	516	514	511	514	503
SD	43	22	25	34	39	27	22	39	32	45
Older Mean	489	476	491	503	497	504	501	499	509	506
SD	25	48	40	20	38	32	38	34	24	35
Session 1 Mean	**492**	**494**	**502**	**506**	**504**	**510**	**508**	**505**	**511**	**505**
SD	**35**	**41**	**34**	**27**	**38**	**30**	**31**	**36**	**28**	**40**
Session 2										
Younger Mean	506	516	510	508	487	505	506	494	472	502
SD	22	23	28	41	81	36	33	71	114	49
Older Mean	486	491	477	495	505	482	500	497	509	504
SD	21	31	45	31	23	44	32	35	28	30
Session 2 Mean	**496**	**503**	**493**	**502**	**496**	**493**	**503**	**496**	**491**	**503**
SD	**24**	**29**	**40**	**36**	**59**	**41**	**32**	**54**	**83**	**39**
Session 3										
Younger Mean	497	518	520	512	501	494	497	498	501	506
SD	39	19	21	35	69	39	52	61	36	36
Older Mean	486	482	492	487	501	464	501	502	507	507
SD	30	35	33	48	31	67	33	30	38	36
Session 3 Mean	**492**	**500**	**506**	**500**	**501**	**479**	**499**	**500**	**504**	**507**
SD	**34**	**33**	**31**	**43**	**52**	**55**	**42**	**47**	**36**	**35**

Table 8
MANOVA Summary Table for Passive Composite Scores

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	14451.51	14451.51	N.S.
Between Subjects	18	601116.63	33395.37	
Day of Study	9	7532.08	836.90	N.S.
Age by Day	9	27721.67	3080.19	3.45**
Within Subjects	162	144596.73	892.57	
Session	2	4178.61	2089.31	N.S.
Age by Session	2	1181.83	590.91	N.S.
Within Subjects	36	29194.93	810.97	
Day by Session	18	15523.61	862.42	2.03 *
Age by Day by Session	18	10426.85	579.27	N.S.
Within Subjects	324	137469.23	424.29	

*p<.05
**p<.001

Table 9

Means and Standard Deviations for MTPB Active Composite Scores

SHIFT		DAY			2-2-1				DAY		
Study Day		**CD1**	**A1**	**A2**	**D1**	**D2**	**N**	**CD2**	**CD3**	**CD4**	**CD5**
Active Composite											
Session 1											
Younger	Mean	481	497	523	519	518	492	504	506	496	525
	SD	48	42	33	36	40	66	51	53	62	42
Older	Mean	452	472	472	494	506	504	494	513	513	514
	SD	55	56	56	35	37	37	49	51	37	27
Overall	**Mean**	**467**	**484**	**498**	**506**	**512**	**498**	**499**	**510**	**505**	**520**
	SD	**53**	**50**	**52**	**37**	**38**	**53**	**49**	**51**	**50**	**35**
Session 2											
Younger	Mean	494	501	512	524	494	485	490	510	471	514
	SD	51	43	41	40	59	61	73	55	127	38
Older	Mean	474	484	496	494	508	470	495	514	514	516
	SD	54	37	28	50	41	86	40	33	23	49
Overall	**Mean**	**484**	**493**	**504**	**509**	**501**	**478**	**493**	**512**	**492**	**515**
	SD	**52**	**40**	**35**	**47**	**50**	**82**	**57**	**44**	**92**	**43**
Session 3											
Younger	Mean	496	509	523	525	506	474	507	511	502	511
	SD	40	37	37	45	66	93	55	61	50	52
Older	Mean	478	473	496	509	504	454	511	517	522	516
	SD	45	66	54	34	38	89	38	49	30	46
Overall	**Mean**	**487**	**491**	**510**	**517**	**505**	**464**	**509**	**514**	**512**	**514**
	SD	**43**	**55**	**47**	**40**	**53**	**89**	**46**	**54**	**41**	**48**

Table 10

MANOVA Summary Table for Active Composite Scores

Source of Variation	**Degrees of Freedom**	**Sums of Squares**	**Mean Squares**	**F**
Age	1	9986.13	9986.13	N.S.
Between Subjects	18	1025358.94	56964.39	
Day of Study	9	91672.86	10185.87	6.50**
Age by Day	9	42891.19	4765.69	3.04*
Within Subjects	162	253854.70	1567.00	
Session	2	1781.51	890.75	N.S.
Age by Session	2	2369.08	1184.54	N.S.
Within Subjects	36	27502.95	763.97	
Day by Session	18	26540.50	1474.49	2.33*
Age by Day by Session	18	11069.58	614.98	N.S.
Within Subjects	324	204920.50	632.47	

*$p<.05$

**$p<.001$

Table 11

Means and Standard Deviations for Arithmetic Percent Correct

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	94.1	95.6	96.0	97.6	96.1	96.1	96.3	96.1	96.3	98.5
	SD	5.5	1.7	2.7	2.4	2.3	3.6	2.9	3.7	1.6	1.7
Older	Mean	91.1	90.1	91.5	93.7	94.7	95.3	93.7	96.9	95.4	96.0
	SD	6.9	6.6	8.1	5.1	3.4	4.7	4.5	3.7	2.9	3.9
Session 1	**Mean**	**92.6**	**92.9**	**93.7**	**95.7**	**95.4**	**95.7**	**95.0**	**96.5**	**95.9**	**97.2**
	SD	**6.3**	**5.4**	**6.3**	**4.4**	**2.9**	**4.1**	**3.9**	**3.6**	**2.3**	**3.2**
Session 2											
Younger	Mean	95.9	95.4	97.3	98.0	96.1	97.6	96.4	96.6	96.9	96.8
	SD	3.6	4.4	2.8	1.6	3.0	2.2	4.6	4.1	3.4	3.1
Older	Mean	92.7	93.0	95.0	95.4	96.5	96.6	94.4	95.1	95.1	96.9
	SD	5.3	3.7	5.7	4.5	3.5	3.6	4.3	4.5	3.0	3.4
Session 2	**Mean**	**94.3**	**94.2**	**96.2**	**96.7**	**96.3**	**97.1**	**95.4**	**95.8**	**96.0**	**96.9**
	SD	**4.7**	**4.1**	**4.5**	**3.5**	**3.2**	**3.0**	**4.5**	**4.3**	**3.3**	**3.2**
Session 3											
Younger	Mean	95.3	97.0	97.1	97.5	95.9	98.3	97.1	98.0	96.8	96.6
	SD	4.3	2.2	2.8	1.7	3.7	2.0	3.3	2.5	1.9	2.9
Older	Mean	94.1	93.5	94.9	94.6	96.1	95.4	96.3	96.1	95.8	95.8
	SD	4.7	5.3	6.1	4.2	2.7	2.4	2.5	4.4	4.5	5.7
Session 3	**Mean**	**94.7**	**95.2**	**96.0**	**96.0**	**96.0**	**96.9**	**96.7**	**97.0**	**96.3**	**96.2**
	SD	**4.4**	**4.3**	**4.8**	**3.4**	**3.1**	**2.6**	**2.9**	**3.6**	**3.4**	**4.4**

Table 12

MANOVA Summary Table for Arithmetic Percent Correct

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	548.65	548.65	N.S.
Between Subjects	18	4125.04	229.17	
Day of Study	9	529.46	58.83	6.25 **
Age by Day	9	170.41	18.93	2.01*
Within Subjects	162	1524.38	9.41	
Session	2	122.67	61.33	7.39*
Age by Session	2	18.91	9.45	N.S.
Within Subjects	36	298.62	8.29	
Day by Session	18	157.26	8.74	N.S.
Age by Day by Session	18	113.94	6.33	N.S.
Within Subjects	324	2486.46	7.67	

*p<.05

**p<.001

Table 13

Means and Standard Deviations for Arithmetic Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	8.5	8.5	7.8	7.7	7.8	8.3	8.7	8.4	8.9	8.2
	SD	1.6	1.9	1.7	1.6	1.9	2.2	2.5	2.2	2.3	1.8
Older	Mean	9.3	8.8	8.6	8.6	8.4	8.7	8.3	8.4	8.1	8.5
	SD	1.7	1.6	1.4	1.6	1.5	1.5	1.7	1.9	1.3	1.2
Overall	**Mean**	**8.9**	**8.6**	**8.2**	**8.2**	**8.1**	**8.5**	**8.5**	**8.4**	**8.5**	**8.3**
	SD	**1.6**	**1.7**	**1.6**	**1.6**	**1.7**	**1.9**	**2.1**	**2.0**	**1.8**	**1.5**
Session 2											
Younger	Mean	8.1	7.9	7.6	7.6	8.5	8.5	8.0	8.0	8.5	8.0
	SD	1.5	1.7	1.5	1.5	2.0	2.4	1.9	2.0	2.2	1.6
Older	Mean	8.9	8.6	8.6	8.3	8.2	8.5	8.3	8.1	7.9	8.1
	SD	1.8	1.9	1.5	1.5	1.4	1.7	1.4	1.5	1.3	1.5
Overall	**Mean**	**8.5**	**8.2**	**8.1**	**7.9**	**8.4**	**8.5**	**8.2**	**8.1**	**8.2**	**8.1**
	SD	**1.7**	**1.8**	**1.5**	**1.5**	**1.7**	**2.0**	**1.6**	**1.7**	**1.8**	**1.5**
Session 3											
Younger	Mean	7.9	8.0	7.8	7.6	7.9	8.5	8.2	8.1	7.8	7.9
	SD	1.4	1.3	1.6	1.6	1.8	1.8	2.1	2.4	1.6	1.9
Older	Mean	8.9	9.0	8.5	8.4	8.3	8.9	8.4	8.0	7.8	8.1
	SD	1.8	2.0	1.7	1.5	1.4	1.8	1.6	1.5	1.1	1.5
Overall	**Mean**	**8.4**	**8.5**	**8.1**	**8.0**	**8.1**	**8.7**	**8.3**	**8.0**	**7.8**	**8.0**
	SD	**1.6**	**1.8**	**1.6**	**1.6**	**1.6**	**1.8**	**1.8**	**2.0**	**1.3**	**1.7**

Table 14

MANOVA Summary Table for Arithmetic Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	17.86	17.86	N.S.
Between Subjects	18	1384.46	76.91	
Day of Study	9	21.61	2.40	3.27**
Age by Day	9	26.90	2.99	4.07 **
Within Subjects	162	118.90	.73	
Session	2	6.37	3.18	12.86**
Age by Session	2	.98	.49	N.S.
Within Subjects	36	8.91	.25	
Day by Session	18	9.00	.50	N.S.
Age by Day by Session	18	6.84	.38	N.S.
Within Subjects	324	105.52	.33	

*p<.05

**p<.001

Table 15
Means and Standard Deviations for Code Lock Solution Percent Correct

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	98.2	97.7	98.8	97.9	98.5	98.0	98.3	98.1	97.8	98.5
	SD	1.2	1.1	0.6	1.8	0.6	1.7	0.8	1.5	1.4	1.3
Older	Mean	94.7	96.0	95.8	96.8	97.3	97.5	96.6	96.4	97.0	97.0
	SD	4.9	2.3	3.9	3.0	2.8	2.0	3.0	4.0	3.1	3.1
Session 1	**Mean**	**96.4**	**96.8**	**97.3**	**97.4**	**97.9**	**97.7**	**97.5**	**97.3**	**97.4**	**97.8**
	SD	**3.9**	**1.9**	**3.1**	**2.4**	**2.1**	**1.8**	**2.3**	**3.1**	**2.4**	**2.4**
Session 2											
Younger	Mean	97.6	98.3	98.2	98.2	97.6	98.4	96.9	98.2	97.5	97.9
	SD	1.8	0.8	1.3	1.1	0.8	1.1	2.7	0.7	1.5	1.1
Older	Mean	96.0	96.5	97.0	96.2	96.8	96.0	96.1	97.5	96.3	97.0
	SD	3.7	2.1	2.4	4.0	2.5	2.7	3.0	2.4	3.0	3.2
Session 2	**Mean**	**96.8**	**97.4**	**97.6**	**97.2**	**97.2**	**97.2**	**96.5**	**97.9**	**96.9**	**97.5**
	SD	**2.9**	**1.8**	**2.0**	**3.0**	**1.9**	**2.4**	**2.8**	**1.8**	**2.4**	**2.4**
Session 3											
Younger	Mean	98.1	98.4	98.7	98.3	97.8	97.0	98.4	98.2	97.7	97.3
	SD	1.0	1.1	0.5	1.5	0.8	2.5	0.9	0.6	1.0	1.9
Older	Mean	94.6	96.7	96.7	97.3	97.2	95.7	97.1	97.1	97.6	97.5
	SD	3.0	2.4	2.6	2.7	2.4	3.7	2.4	4.0	2.5	2.6
Session 3	**Mean**	**96.4**	**97.5**	**97.7**	**97.8**	**97.5**	**96.3**	**97.8**	**97.6**	**97.6**	**97.4**
	SD	**2.8**	**2.0**	**2.1**	**2.2**	**1.7**	**3.2**	**1.9**	**2.8**	**1.9**	**2.2**

Table 16
MANOVA Summary Table for Code Lock Solution Percent Correct

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	303.23	303.23	N.S.
Between Subjects	18	1994.15	110.79	
Day of Study	9	54.93	6.10	N.S.
Age by Day	9	59.24	6.58	2.02*
Within Subjects	162	527.21	3.25	
Session	2	2.91	1.45	N.S.
Age by Session	2	4.76	2.38	N.S.
Within Subjects	36	56.15	1.56	
Day by Session	18	65.97	3.66	2.87**
Age by Day by Session	18	43.37	2.41	1.88*
Within Subjects	324	414.25	1.28	

*$p<.05$
**$p<.001$

Table 17
Means and Standard Deviations for Code Lock Solution Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	17.3	14.9	13.3	14.0	13.8	14.8	14.9	13.4	14.3	13.0
	SD	7.9	5.8	3.8	5.3	4.6	4.5	5.8	4.3	3.6	3.1
Older	Mean	20.1	17.8	16.8	14.7	14.7	14.2	14.4	14.8	13.9	13.5
	SD	6.9	5.9	4.7	3.0	3.6	3.1	3.3	3.6	2.9	2.5
Session 1	**Mean**	**18.7**	**16.4**	**15.1**	**14.3**	**14.3**	**14.5**	**14.6**	**14.1**	**14.1**	**13.2**
	SD	**7.4**	**5.9**	**4.5**	**4.2**	**4.1**	**3.8**	**4.6**	**3.9**	**3.1**	**2.8**
Session 2											
Younger	Mean	16.7	14.4	13.4	14.1	14.2	14.3	14.1	13.4	16.0	13.0
	SD	8.0	4.5	3.9	5.2	4.4	4.5	4.6	3.6	9.2	3.1
Older	Mean	18.2	15.3	14.4	15.0	14.2	16.3	14.9	13.7	13.5	13.2
	SD	6.9	3.9	3.1	3.0	3.0	4.5	2.7	2.8	2.0	2.3
Session 2	**Mean**	**17.4**	**14.8**	**13.9**	**14.5**	**14.2**	**15.3**	**14.5**	**13.5**	**14.8**	**13.1**
	SD	**7.3**	**4.1**	**3.5**	**4.2**	**3.7**	**4.5**	**3.7**	**3.1**	**6.6**	**2.7**
Session 3											
Younger	Mean	15.4	14.3	13.5	12.8	13.7	15.4	13.3	12.5	12.8	12.5
	SD	6.6	4.2	4.5	3.1	3.8	4.3	3.4	2.7	2.4	2.3
Older	Mean	16.6	15.7	14.7	14.3	13.9	16.7	14.4	13.4	13.1	12.8
	SD	4.1	5.0	3.1	3.6	2.9	5.0	3.6	2.7	2.3	1.9
Session 3	**Mean**	**16.0**	**15.0**	**14.1**	**13.6**	**13.8**	**16.1**	**13.8**	**12.9**	**12.9**	**12.7**
	SD	**5.4**	**4.5**	**3.8**	**3.3**	**3.3**	**4.6**	**3.5**	**2.7**	**2.3**	**2.1**

Table 18
MANOVA Summary Table for Code Lock Solution Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	109.35	109.35	N.S.
Between Subjects	18	6977.95	387.66	
Day of Study	9	814.82	90.54	8.05**
Age by Day	9	96.79	10.75	N.S.
Within Subjects	162	1822.93	11.25	
Session	2	70.38	35.19	5.76*
Age by Session	2	11.28	5.64	N.S.
Within Subjects	36	219.99	6.11	
Day by Session	18	140.73	7.82	2.06*
Age by Day by Session	18	79.74	4.43	N.S.
Within Subjects	324	1228.37	3.79	

*p<.05
**p<.001

Table 19

Means and Standard Deviations for Code Lock Recall Percent Correct

Study Day		**CD1**	**A1**	**A2**	**D1**	**D2**	**N**	**CD2**	**CD3**	**CD4**	**CD5**
Session 1											
Younger	Mean	96.4	96.8	98.0	97.2	97.1	95.6	96.5	96.9	95.1	97.0
	SD	3.2	3.8	1.3	2.6	2.2	4.2	2.6	4.2	4.3	3.8
Older	Mean	92.5	95.2	93.9	95.2	95.6	94.9	93.6	96.1	96.6	96.1
	SD	5.8	2.3	3.1	2.4	2.3	2.7	4.5	3.5	2.6	3.0
Session 1	**Mean**	**94.5**	**96.0**	**96.0**	**96.2**	**96.4**	**95.2**	**95.1**	**96.5**	**95.8**	**96.6**
	SD	**5.0**	**3.2**	**3.1**	**2.6**	**2.3**	**3.4**	**3.9**	**3.8**	**3.6**	**3.4**
Session 2											
Younger	Mean	97.5	96.4	96.9	97.6	96.2	94.8	95.6	96.3	94.4	96.2
	SD	2.2	3.1	2.9	1.5	3.7	6.4	3.4	2.8	7.4	3.4
Older	Mean	95.0	92.5	94.5	93.4	95.2	92.3	94.8	96.8	96.0	96.6
	SD	2.5	3.1	2.2	3.0	2.7	3.6	3.4	3.3	2.3	2.4
Session 2	**Mean**	**96.3**	**94.5**	**95.7**	**95.5**	**95.7**	**93.5**	**95.2**	**96.6**	**95.2**	**96.4**
	SD	**2.6**	**3.6**	**2.8**	**3.2**	**3.2**	**5.2**	**3.3**	**3.0**	**5.4**	**2.9**
Session 3											
Younger	Mean	96.2	97.8	98.5	97.4	96.5	95.8	96.1	97.0	95.4	96.0
	SD	3.5	1.7	1.2	2.1	3.2	4.4	4.5	3.7	3.4	4.5
Older	Mean	93.1	94.0	94.6	97.1	94.6	90.3	95.7	96.5	96.8	95.9
	SD	3.3	3.0	2.3	2.2	3.4	6.1	1.6	2.9	2.7	4.0
Session 3	**Mean**	**94.7**	**95.9**	**96.5**	**97.2**	**95.5**	**93.0**	**95.9**	**96.8**	**96.1**	**96.0**
	SD	**3.7**	**3.1**	**2.7**	**2.1**	**3.3**	**5.9**	**3.3**	**3.3**	**3.1**	**4.1**

Table 20

MANOVA Summary Table for Code Lock Recall Percent Correct

Source of Variation	**Degrees of Freedom**	**Sums of Squares**	**Mean Squares**	**F**
Age	1	408.03	408.03	N.S.
Between Subjects	18	2028.89	112.72	
Day of Study	9	321.34	35.70	3.62**
Age by Day	9	352.28	39.14	3.97**
Within Subjects	162	1596.22	9.85	
Session	2	14.94	7.47	N.S.
Age by Session	2	3.09	1.54	N.S.
Within Subjects	36	361.43	10.04	
Day by Session	18	170.92	9.50	N.S.
Age by Day by Session	18	154.24	8.57	N.S.
Within Subjects	324	2360.96	7.29	

*p<.05
**p<.001

Table 21
Means and Standard Deviations for Code Lock Recall Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	5.7	4.9	4.5	4.8	4.8	5.6	4.9	5.0	5.3	5.0
	SD	1.8	1.6	1.2	1.0	1.0	1.8	1.4	1.7	1.7	1.8
Older	Mean	5.9	5.0	5.5	5.0	4.9	5.1	5.3	4.9	4.4	4.5
	SD	1.5	1.3	1.5	1.2	1.4	1.4	1.8	1.8	1.2	1.0
Session 1	**Mean**	**5.8**	**5.0**	**5.0**	**4.9**	**4.8**	**5.4**	**5.1**	**5.0**	**4.9**	**4.7**
	SD	**1.6**	**1.4**	**1.5**	**1.1**	**1.2**	**1.6**	**1.6**	**1.7**	**1.5**	**1.4**
Session 2											
Younger	Mean	4.9	4.7	4.6	4.4	5.1	5.6	5.0	4.7	8.0	4.9
	SD	1.4	1.0	0.9	1.0	1.8	2.3	1.7	1.2	9.4	1.0
Older	Mean	5.4	5.2	5.4	5.4	4.9	6.2	4.8	4.9	4.9	4.5
	SD	1.1	1.0	1.0	1.4	1.5	2.7	1.3	1.1	1.2	1.2
Session 2	**Mean**	**5.1**	**5.0**	**5.0**	**4.9**	**5.0**	**5.9**	**4.9**	**4.8**	**6.5**	**4.7**
	SD	**1.3**	**1.0**	**1.0**	**1.3**	**1.6**	**2.4**	**1.5**	**1.2**	**6.7**	**1.1**
Session 3											
Younger	Mean	5.0	4.6	4.4	4.4	5.0	5.6	5.0	4.8	5.4	4.9
	SD	1.4	1.0	1.0	1.1	1.2	1.7	1.4	1.3	1.3	1.4
Older	Mean	5.4	5.6	4.7	4.6	5.4	7.0	4.9	4.6	4.3	4.7
	SD	1.4	1.6	1.3	1.4	1.5	3.2	1.4	1.2	0.9	1.5
Session 3	**Mean**	**5.2**	**5.1**	**4.5**	**4.5**	**5.2**	**6.3**	**5.0**	**4.7**	**4.9**	**4.8**
	SD	**1.4**	**1.4**	**1.2**	**1.3**	**1.4**	**2.6**	**1.3**	**1.2**	**1.2**	**1.4**

Table 22
MANOVA Summary Table for Code Lock Recall Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	.72	.72	N.S.
Between Subjects	18	772.78	42.93	
Day of Study	9	66.94	7.44	2.92*
Age by Day	9	66.80	7.42	2.91*
Within Subjects	162	412.66	2.55	
Session	2	3.14	1.57	N.S.
Age by Session	2	1.54	.77	N.S.
Within Subjects	36	102.57	2.85	
Day by Session	18	52.02	2.89	N.S.
Age by Day by Session	18	29.65	1.65	N.S.
Within Subjects	324	650.37	2.01	

*p<.05
**p<.001

Table 23

Means and Standard Deviations for Target Identification Percent Correct

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	86.8	87.0	91.2	88.5	89.6	85.8	90.6	88.7	88.5	91.4
	SD	8.1	7.7	8.0	8.1	6.7	10.7	6.4	7.5	10.6	5.9
Older	Mean	88.5	89.8	89.5	90.7	92.7	92.4	91.9	93.1	91.9	93.8
	SD	5.6	6.0	3.9	7.1	3.5	3.5	4.8	4.6	5.1	3.9
Session 1	**Mean**	**87.7**	**88.5**	**90.3**	**89.7**	**91.2**	**89.3**	**91.3**	**91.0**	**90.3**	**92.7**
	SD	**6.7**	**6.8**	**6.1**	**7.5**	**5.3**	**8.3**	**5.5**	**6.4**	**8.1**	**5.0**
Session 2											
Younger	Mean	86.4	85.1	88.1	89.9	87.2	80.7	85.8	88.7	84.5	90.6
	SD	12.3	8.6	8.9	6.6	8.0	15.2	12.5	9.2	13.3	6.9
Older	Mean	89.0	90.5	91.2	92.1	92.4	85.0	90.4	93.5	92.4	92.1
	SD	5.7	5.0	4.3	4.6	4.1	12.2	6.5	3.6	3.5	4.5
Session 2	**Mean**	**87.8**	**87.9**	**89.8**	**91.0**	**90.0**	**83.0**	**88.2**	**91.2**	**88.7**	**91.4**
	SD	**9.3**	**7.3**	**6.8**	**5.6**	**6.6**	**13.5**	**9.8**	**7.1**	**10.0**	**5.7**
Session 3											
Younger	Mean	86.2	87.8	88.5	88.9	87.6	81.8	85.6	86.2	84.7	89.1
	SD	7.8	6.2	7.8	8.5	12.1	17.3	7.8	8.8	10.8	7.1
Older	Mean	89.8	87.6	90.7	93.3	90.2	85.7	93.2	92.1	92.3	92.6
	SD	5.4	8.0	4.9	4.1	4.8	8.5	4.9	5.6	3.5	5.6
Session 3	**Mean**	**88.1**	**87.7**	**89.7**	**91.2**	**89.0**	**83.9**	**89.6**	**89.3**	**88.7**	**90.9**
	SD	**6.7**	**7.0**	**6.3**	**6.8**	**8.8**	**13.2**	**7.4**	**7.7**	**8.5**	**6.4**

Table 24

MANOVA Summary Table for Target Identification Percent Correct

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	1871.99	1871.99	N.S.
Between Subjects	17	16320.33	960.02	
Day of Study	9	1676.38	186.26	4.42**
Age by Day	9	301.77	33.53	N.S.
Within Subjects	153	6447.72	42.14	
Session	2	241.99	120.99	6.20*
Age by Session	2	72.79	36.40	N.S.
Within Subjects	34	663.18	19.51	
Day by Session	18	491.95	27.33	N.S.
Age by Day by Session	18	294.10	16.34	N.S.
Within Subjects	324	6827.47	22.31	

*p<.05
**p<.001

Table 25

Means and Standard Deviations for Target Identification Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	2.4	2.2	2.1	2.2	2.1	2.4	2.2	2.2	2.3	2.1
	SD	0.7	0.4	0.3	0.3	0.3	0.7	0.3	0.3	0.4	0.3
Older	Mean	2.2	2.1	2.2	2.1	2.1	2.0	2.1	2.0	2.0	2.0
	SD	0.4	.04	0.5	0.4	0.3	0.4	0.4	0.5	0.4	0.4
Session 1	**Mean**	**2.3**	**2.1**	**2.2**	**2.1**	**2.1**	**2.2**	**2.2**	**2.1**	**2.1**	**2.1**
	SD	**0.6**	**0.4**	**0.4**	**0.3**	**0.3**	**0.5**	**0.4**	**0.4**	**0.4**	**0.3**
Session 2											
Younger	Mean	2.4	2.2	2.4	2.2	2.4	2.4	2.6	2.2	2.7	2.2
	SD	0.6	0.4	0.4	0.3	0.6	0.5	0.8	0.4	1.3	0.3
Older	Mean	2.1	2.1	2.1	2.3	2.2	2.5	2.1	2.1	2.0	2.1
	SD	0.5	0.4	0.4	0.5	0.4	1.2	0.5	0.4	0.4	0.5
Session 2	**Mean**	**2.3**	**2.2**	**2.3**	**2.2**	**2.3**	**2.5**	**2.4**	**2.2**	**2.3**	**2.2**
	SD	**0.5**	**0.4**	**0.4**	**0.4**	**0.5**	**0.9**	**0.7**	**0.4**	**1.0**	**0.4**
Session 3											
Younger	Mean	2.4	2.4	2.2	2.2	2.3	2.8	2.2	2.3	2.3	2.2
	SD	0.4	0.3	0.2	0.4	0.6	1.0	0.4	0.5	0.5	0.4
Older	Mean	2.1	2.3	2.1	2.1	2.1	2.6	2.1	2.0	2.0	2.1
	SD	0.4	0.6	0.5	0.4	0.4	1.1	0.5	0.5	0.4	0.5
Session 3	**Mean**	**2.2**	**2.3**	**2.2**	**2.1**	**2.2**	**2.7**	**2.2**	**2.2**	**2.1**	**2.1**
	SD	**0.4**	**0.5**	**0.4**	**0.4**	**0.5**	**1.0**	**0.5**	**0.5**	**0.4**	**0.5**

Table 26

MANOVA Summary Table for Target Identification Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	4.73	4.73	N.S.
Between Subjects	17	86.55	5.09	
Day of Study	9	4.38	.49	2.54*
Age by Day	9	1.63	.18	N.S.
Within Subjects	153	29.32	.19	
Session	2	1.39	.70	6.14*
Age by Session	2	.18	.09	N.S.
Within Subjects	34	3.85	.11	
Day by Session	18	3.00	.17	2.50**
Age by Day by Session	18	2.16	.12	1.80*
Within Subjects	306	20.37	.07	

*p<.05

**p<.001

Table 27

Means and Standard Deviations for Probability Meters Percent Correct

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	94.1	95.1	97.0	95.1	96.5	96.0	96.2	95.3	96.0	95.8
	SD	9.2	7.6	4.9	8.8	7.5	4.0	5.3	9.0	8.3	8.8
Older	Mean	94.5	90.9	91.6	95.9	94.3	93.9	94.3	92.8	95.1	93.4
	SD	5.2	9.7	11.8	5.5	9.8	11.0	10.5	10.4	9.0	12.9
Session 1	**Mean**	**94.3**	**93.0**	**94.3**	**95.5**	**95.4**	**94.9**	**95.3**	**94.1**	**95.6**	**94.6**
	SD	**7.3**	**8.8**	**9.2**	**7.1**	**8.6**	**8.1**	**8.2**	**9.6**	**8.4**	**10.8**
Session 2											
Younger	Mean	96.5	97.3	97.7	97.2	94.7	94.9	95.3	95.3	91.3	94.8
	SD	6.7	4.2	4.2	5.3	9.5	8.1	6.2	8.3	14.5	8.2
Older	Mean	93.1	94.8	92.5	94.4	93.3	91.0	94.0	92.6	95.5	93.5
	SD	5.5	6.7	9.4	9.9	8.1	16.9	12.2	11.8	10.6	11.1
Session 2	**Mean**	**94.8**	**96.0**	**95.1**	**95.8**	**94.0**	**93.0**	**94.6**	**93.9**	**93.4**	**94.2**
	SD	**6.2**	**5.6**	**7.6**	**7.9**	**8.7**	**13.1**	**9.4**	**10.0**	**12.6**	**9.5**
Session 3											
Younger	Mean	95.9	97.3	98.3	95.9	95.5	92.3	96.4	94.1	95.4	93.7
	SD	4.4	2.9	3.4	7.4	8.5	10.7	6.6	13.6	9.2	10.8
Older	Mean	93.6	93.6	93.1	94.0	92.9	88.1	93.8	94.5	95.2	93.7
	SD	7.2	6.9	12.2	11.9	12.0	18.3	10.0	12.3	10.6	15.2
Session 3	**Mean**	**94.8**	**95.5**	**95.7**	**94.9**	**94.2**	**90.2**	**95.1**	**94.3**	**95.3**	**93.7**
	SD	**6.0**	**5.5**	**9.1**	**9.7**	**10.2**	**14.7**	**8.4**	**12.6**	**9.7**	**12.8**

Table 28

MANOVA Summary Table for Probability Meters Percent Correct

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	663.58	663.58	N.S.
Between Subjects	18	38923.65	2162.42	
Day of Study	9	306.88	34.10	N.S.
Age by Day	9	381.09	42.34	N.S.
Within Subjects	162	5835.53	36.02	
Session	2	10.38	5.19	N.S.
Age by Session	2	1.26	.63	N.S.
Within Subjects	36	612.58	17.02	
Day by Session	18	444.29	24.68	1.90*
Age by Day by Session	18	224.36	12.46	N.S.
Within Subjects	324	4213.61	13.00	

*p<.05
**p<.001

Table 29

Means and Standard Deviations for Probability Meters Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	10.4	9.3	9.1	9.9	9.3	9.3	9.4	9.4	9.5	10.3
	SD	3.3	2.9	2.2	3.8	3.2	3.1	2.8	3.4	3.5	3.7
Older	Mean	10.3	10.5	10.9	10.0	10.1	10.1	10.0	10.4	9.8	10.0
	SD	2.6	3.8	4.5	3.0	3.8	4.0	3.7	4.1	3.6	4.6
Session 1	**Mean**	**10.4**	**9.9**	**10.0**	**9.9**	**9.7**	**9.7**	**9.7**	**9.9**	**9.6**	**10.1**
	SD	**2.9**	**3.3**	**3.6**	**3.3**	**3.4**	**3.5**	**3.2**	**3.7**	**3.5**	**4.1**
Session 2											
Younger	Mean	9.7	8.8	9.1	9.4	10.1	9.8	10.0	9.8	10.6	9.8
	SD	2.8	2.5	2.6	3.2	3.8	3.7	3.2	3.9	4.5	3.7
Older	Mean	11.5	10.3	10.8	10.0	10.2	11.3	10.7	10.4	9.4	9.8
	SD	2.8	3.3	3.6	3.9	3.5	4.7	4.5	4.2	4.0	4.7
Session 2	**Mean**	**10.6**	**9.6**	**9.9**	**9.7**	**10.1**	**10.6**	**10.4**	**10.1**	**10.0**	**9.8**
	SD	**2.9**	**3.0**	**3.2**	**3.5**	**3.6**	**4.2**	**3.8**	**3.9**	**4.2**	**4.1**
Session 3											
Younger	Mean	9.9	9.0	8.7	9.1	9.6	10.9	10.1	9.8	10.4	9.9
	SD	2.8	2.5	2.5	2.6	4.0	3.9	3.9	4.5	4.0	4.0
Older	Mean	10.5	11.3	10.9	11.0	10.3	12.5	10.3	9.8	9.6	10.2
	SD	3.2	3.4	4.3	4.3	4.3	5.7	4.5	4.5	4.4	5.1
Session 3	**Mean**	**10.2**	**10.2**	**9.8**	**10.1**	**9.9**	**11.7**	**10.2**	**9.8**	**10.0**	**10.1**
	SD	**2.9**	**3.2**	**3.6**	**3.6**	**4.1**	**4.8**	**4.1**	**4.4**	**4.1**	**4.5**

Table 30

MANOVA Summary Table for Probability Meters Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	85.59	85.59	N.S.
Between Subjects	18	6731.55	373.97	
Day of Study	9	35.06	3.90	N.S.
Age by Day	9	74.46	8.27	2.65*
Within Subjects	162	505.53	3.12	
Session	2	8.74	4.37	N.S.
Age by Session	2	2.17	1.08	N.S.
Within Subjects	36	51.36	1.43	
Day by Session	18	49.83	2.77	2.71**
Age by Day by Session	18	34.36	1.91	N.S.
Within Subjects	324	330.92	1.02	

*p<.05
**p<.001

Table 31

Means and Standard Deviations for Red Warning Lights Percent Correct

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	99.6	100.0	100.0	100.0	99.7	100.0	100.0	100.0	100.0	100.0
	SD	1.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Older	Mean	100.0	100.0	100.0	100.0	99.5	100.0	100.0	99.5	100.0	100.0
	SD	0.0	0.0	0.0	0.0	1.5	0.0	0.0	1.5	0.0	0.0
Session 1	**Mean**	**99.8**	**100.0**	**100.0**	**100.0**	**99.6**	**100.0**	**100.0**	**99.8**	**100.0**	**100.0**
	SD	**0.8**	**0.0**	**0.0**	**0.0**	**1.2**	**0.0**	**0.0**	**1.1**	**0.0**	**0.0**
Session 2											
Younger	Mean	100.0	100.0	100.0	99.3	98.3	100.0	100.0	99.3	98.2	99.2
	SD	0.0	0.0	0.0	2.3	4.0	0.0	0.0	1.4	4.6	1.8
Older	Mean	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	SD	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Session 2	**Mean**	**99.8**	**100.0**	**100.0**	**99.6**	**99.2**	**100.0**	**100.0**	**99.7**	**99.1**	**99.6**
	SD	**1.1**	**0.0**	**0.0**	**1.6**	**2.9**	**0.0**	**0.0**	**1.0**	**3.3**	**1.3**
Session 3											
Younger	Mean	99.1	100.0	100.0	99.7	99.8	100.0	98.6	100.0	99.6	100.0
	SD	3.0	0.0	0.0	1.0	0.8	0.0	3.2	0.0	1.3	0.0
Older	Mean	99.7	100.0	100.0	99.5	100.0	100.0	100.0	100.0	99.6	100.0
	SD	1.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	1.1	0.0
Session 3	**Mean**	**99.4**	**100.0**	**100.0**	**99.6**	**100.0**	**100.0**	**99.3**	**100.0**	**99.6**	**100.0**
	SD	**2.2**	**0.0**	**0.0**	**1.2**	**0.6**	**0.0**	**2.3**	**0.0**	**1.2**	**0.0**

Table 32

MANOVA Summary Table for Red Warning Lights Percent Correct

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	8.53	8.53	N.S.
Between Subjects	18	72.08	4.00	
Day of Study	9	16.09	1.79	N.S.
Age by Day	9	8.18	.91	N.S.
Within Subjects	162	194.21	1.20	
Session	2	5.34	2.67	N.S.
Age by Session	2	7.65	3.83	N.S.
Within Subjects	36	72.85	2.02	
Day by Session	18	22.87	1.27	N.S.
Age by Day by Session	18	30.39	1.69	N.S.
Within Subjects	324	410.68	1.27	

*p<.05
**p<.001

Table 33

Means and Standard Deviations for Red Warning Lights Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	1.8	1.7	1.6	0.6	1.6	1.7	1.7	1.7	1.7	2.0
	SD	0.4	0.4	0.3	0.4	0.5	0.6	0.5	0.5	0.4	0.8
Older	Mean	1.9	2.0	1.6	1.7	1.8	1.6	1.7	1.8	1.6	1.8
	SD	0.4	0.3	0.4	0.3	0 4	0.3	0.4	0.4	0.3	0.5
Session 1	**Mean**	**1.8**	**1.9**	**1.6**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.6**	**1.9**
	SD	**0.4**	**0.4**	**0.3**	**0.3**	**0.4**	**0.5**	**0.4**	**0.5**	**0.4**	**0.7**
Session 2											
Younger	Mean	1.6	1.6	1.7	1.7	2.1	1.9	1.9	2.2	2.3	1.8
	SD	0.4	0.3	0.4	0.7	1.1	0.6	0.7	1.3	1.5	0.6
Older	Mean	2.0	1.9	1.9	1.8	1.7	2.1	1.7	1.8	1.7	1.9
	SD	0.6	0.4	0.6	0.4	0.4	0.7	0.3	0.3	0.4	0.3
Session 2	**Mean**	**1.8**	**1.8**	**1.8**	**1.8**	**1.9**	**2.0**	**1.8**	**2.0**	**2.0**	**1.8**
	SD	**0.5**	**.4**	**.5**	**.5**	**.9**	**.6**	**.5**	**.9**	**1.1**	**.5**
Session 3											
Younger	Mean	1.9	1.6	1.5	1.7	2.0	2.0	2.0	2.0	2.0	1.8
	SD	0.6	0.3	0.4	0.7	1.2	0.5	0.9	0.9	0.5	0.6
Older	Mean	1.8	1.9	1.7	1.8	1.7	2.0	1.7	1.8	1.9	1.7
	SD	0.3	0.5	0.4	0.4	0.4	0.6	0.4	0.5	0.3	0.4
Session 3	**Mean**	**1.9**	**1.7**	**1.6**	**1.8**	**1.9**	**2.0**	**1.9**	**1.9**	**1.9**	**1.7**
	SD	**0.5**	**0.4**	**0.4**	**0.6**	**0.9**	**0.5**	**0.7**	**0.7**	**0.4**	**0.5**

Table 34

MANOVA Summary Table for Red Warning Lights Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	.04	.04	N.S.
Between Subjects	18	97.75	5.43	
Day of Study	9	2.04	.23	N.S.
Age by Day	9	4.75	.53	2.66*
Within Subjects	162	32.10	.20	
Session	2	1.95	.97	6.83*
Age by Session	2	.10	.05	N.S.
Within Subjects	36	5.13	.14	
Day by Session	18	3.74	.21	N.S.
Age by Day by Session	18	2.62	.15	N.S.
Within Subjects	324	44.70	.14	

*p<.05

**p<.001

Table 35

Means and Standard Deviations for Green Warning Lights Percent Correct

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	98.2	99.8	99.3	99.0	99.3	100.0	100.0	99.6	100.0	99.2
	SD	4.6	0.8	2.3	1.6	2.3	0.0	0.0	1.3	0.0	2.6
Older	Mean	96.6	96.4	97.9	99.0	98.0	99.7	99.1	99.5	99.1	100.0
	SD	2.8	4.8	2.7	2.2	3.8	1.0	2.1	1.5	2.0	0.0
Session 1	**Mean**	**97.4**	**98.1**	**98.6**	**99.0**	**98.6**	**99.8**	**99.5**	**99.6**	**99.6**	**99.6**
	SD	**3.8**	**3.8**	**2.5**	**1.9**	**3.1**	**.7**	**1.5**	**1.4**	**1.5**	**1.9**
Session 2											
Younger	Mean	98.1	100.0	98.5	99.4	98.5	100.0	99.6	98.4	96.8	99.4
	SD	3.1	0.0	3.1	2.0	4.7	0.0	1.3	4.9	9.0	2.0
Older	Mean	99.2	98.2	95.7	98.3	99.4	98.4	99.3	98.6	99.4	99.5
	SD	1.8	3.2	6.6	2.7	2.0	2.6	1.5	3.7	2.0	1.5
Session 2	**Mean**	**98.6**	**99.1**	**97.1**	**98.9**	**98.9**	**99.2**	**99.5**	**98.5**	**98.1**	**99.4**
	SD	**2.5**	**2.4**	**5.3**	**2.4**	**3.6**	**1.9**	**1.4**	**4.3**	**6.5**	**1.7**
Session 3											
Younger	Mean	99.3	99.7	99.6	100.0	98.1	99.1	100.0	98.4	99.8	99.6
	SD	2.3	1.0	1.3	0.0	6.0	2.8	0.0	4.9	0.8	1.3
Older	Mean	96.5	97.4	98.3	97.7	99.8	95.7	99.1	98.5	99.8	99.6
	SD	4.1	3.7	3.8	3.3	0.8	6.3	2.8	4.0	0.6	1.3
Session 3	**Mean**	**97.9**	**98.6**	**98.9**	**98.9**	**98.9**	**97.4**	**99.6**	**98.5**	**99.8**	**99.6**
	SD	**3.5**	**2.9**	**2.8**	**2.5**	**4.3**	**5.0**	**2.0**	**4.4**	**0.7**	**1.3**

Table 36

MANOVA Summary Table for Green Warning Lights Percent Correct

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	87.33	87.33	N.S.
Between Subjects	18	881.30	48.96	
Day of Shift	9	136.38	15.15	N.S.
Age by Day	9	154.89	17.21	N.S.
Within Subjects	162	1510.42	9.32	
Session	2	6.25	3.13	N.S.
Age by Session	2	19.15	9.58	N.S.
Within Subjects	36	586.33	16.29	
Day by Session	18	173.96	9.66	N.S.
Age by Day by Session	18	129.38	7.19	N.S.
Within Subjects	324	2108.13	6.51	

*p<.05

**p<.001

Table 37

Means and Standard Deviations for Green Warning Lights Response Time

Study Day		CD1	A1	A2	D1	D2	N	CD2	CD3	CD4	CD5
Session 1											
Younger	Mean	2.7	2.1	2.3	2.2	2.2	1.9	2.0	2.1	2.0	2.1
	SD	1.1	0.3	0.7	0.7	0.7	0.5	0.4	1.2	0.8	0.8
Older	Mean	3.0	3.7	3.0	2.7	2.4	2.7	2.8	2.3	2.4	2.1
	SD	0.9	1.9	1.0	0.7	0.6	0.9	1.1	0.6	0.7	0.6
Session 1	**Mean**	**2.8**	**2.9**	**2.6**	**2.5**	**2.3**	**2.3**	**2.4**	**2.2**	**2.2**	**2.1**
	SD	**1.0**	**1.6**	**0.9**	**0.8**	**0.6**	**0.8**	**0.9**	**0.9**	**0.7**	**0.7**
Session 2											
Younger	Mean	2.4	2.4	2.4	2.2	2.4	2.4	2.1	2.3	2.5	2.2
	SD	0.4	1.3	0.9	0.6	1.4	1.0	0.7	1.7	1.7	0.8
Older	Mean	3.0	3.3	3.7	2.9	2.2	3.0	2.7	2.5	2.3	2.2
	SD	1.2	1.5	1.7	1.2	0.7	1.1	0.7	0.7	0.8	0.5
Session 2	**Mean**	**2.7**	**2.8**	**3.1**	**2.6**	**2.3**	**2.7**	**2.4**	**2.4**	**2.4**	**2.2**
	SD	**0.9**	**1.4**	**1.5**	**1.0**	**1.1**	**1.1**	**0.7**	**1.2**	**1.3**	**0.7**
Session 3											
Younger	Mean	2.6	2.1	2.1	2.0	2.2	2.5	2.2	2.4	2.1	2.0
	SD	0.6	0.5	0.4	0.5	1.2	1.0	0.7	1.5	0.6	0.6
Older	Mean	3.1	3.4	3.1	3.0	2.6	3.6	2.6	2.4	2.1	2,1
	SD	0.7	1.4	1.3	0.9	0.9	2.0	0.8	0.8	0.4	0.7
Session 3	**Mean**	**2.8**	**2.8**	**2.6**	**2.5**	**2.4**	**3.1**	**2.4**	**2.4**	**2.1**	**2.1**
	SD	**0.7**	**1.2**	**1.1**	**0.9**	**1.1**	**1.6**	**0.8**	**1.2**	**0.5**	**0.6**

Table 38

MANOVA Summary Table for Green Warning Lights Response Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	39.13	39.13	N.S.
Between Subjects	18	244.53	13.58	
Day of Study	9	34.38	3.82	4.48**
Age by Day	9	26.32	2.92	3.43**
Within Subjects	162	138.16	.85	
Session	2	1.73	.86	N.S.
Age by Session	2	.46	.23	N.S.
Within Subjects	36	23.63	.66	
Day by Session	18	9.73	.54	N.S.
Age by Day by Session	18	5.41	.30	N.S.
Within Subjects	324	117.24	.36	

*p<.05

**p<.001

Table 39

Means and Standard Deviations for Passive Composite Scores by Session and 15-Minute Interval for the Night Shift

Session Interval			1	2	3	4	5	6	7	8
Session 1										
	Younger	Mean	525	521	506	510	532	509	515	513
		SD	40	25	40	48	13	30	33	41
	Older	Mean	528	527	497	497	515	463	486	520
		SD	20	14	57	47	36	64	57	26
	Overall	**Mean**	**527**	**524**	**501**	**504**	**523**	**486**	**501**	**516**
		SD	**31**	**20**	**48**	**46**	**28**	**54**	**48**	**34**
Session 2										
	Younger	Mean	515	516	508	509	496	488	500	505
		SD	47	44	31	41	47	47	42	47
	Older	Mean	521	518	462	480	463	437	479	491
		SD	35	28	69	61	50	91	68	60
	Overall	**Mean**	**518**	**517**	**485**	**494**	**479**	**462**	**489**	**498**
		SD	**40**	**36**	**57**	**53**	**50**	**75**	**56**	**53**
Session 3										
	Younger	Mean	510	493	487	478	510	466	501	495
		SD	45	53	47	60	30	82	48	45
	Older	Mean	507	488	434	454	437	419	476	502
		SD	48	45	95	101	108	102	68	34
	Overall	**Mean**	**508**	**490**	**461**	**466**	**473**	**442**	**488**	**498**
		SD	**45**	**48**	**78**	**82**	**86**	**93**	**59**	**39**

Table 40

MANOVA Summary Table for Passive Composite Scores by Session and 15-minute Interval for the Night Shift

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	54107.84	54107.84	N.S.
Between Subjects	18	693417.32	38523.18	
Interval (Workload Condition)	7	140687.87	20098.27	9.08**
Age by Interval	7	29017.44	4145.35	N.S.
Within Subjects	126	278982.83	2214.15	
Session	2	2459.56	1229.78	N.S.
Age by Session	2	277.83	138.91	N.S.
Within Subjects	36	53821.17	1495.03	
Interval by Session	14	82143.40	5867.39	5.41**
Age by Interval by Session	14	30656.70	2189.76	2.02*
Within Subjects	252	273399.62	1084.92	

*p<.05
**p<.001

Table 41

Means and Standard Deviations for Active Composite Scores by Session and Interval for the Night Shift

Session Interval			**2**	**3**	**4**	**5**	**6**	**7**
Session 1								
	Younger	Mean	502	506	523	521	479	436
		SD	101	58	38	39	71	167
	Older	Mean	473	492	514	544	494	520
		SD	75	39	44	30	41	60
	Session 1	**Mean**	**488**	**499**	**518**	**533**	**486**	**478**
		SD	**88**	**49**	**40**	**36**	**57**	**129**
Session 2								
	Younger	Mean	523	505	530	503	472	407
		SD	84	73	51	70	93	156
	Older	Mean	509	472	513	508	406	448
		SD	71	72	43	43	125	187
	Session 2	**Mean**	**516**	**488**	**522**	**505**	**439**	**428**
		SD	**76**	**73**	**46**	**56**	**112**	**169**
Session 3								
	Younger	Mean	530	509	522	509	427	391
		SD	65	57	42	63	144	195
	Older	Mean	488	457	464	448	429	428
		SD	83	74	77	154	69	191
	Session 3	**Mean**	**509**	**483**	**493**	**479**	**428**	**409**
		SD	**76**	**70**	**67**	**119**	**110**	**189**

Table 42

MANOVA Summary Table for Active Composite Scores by Session and 15-minute Interval for the Night Shift

Source of Variation	**Degrees of Freedom**	**Sums of Squares**	**Mean Squares**	**F**
Age	1	10049.75	10049.75	N.S.
Between Subjects	18	1510991.60	83943.98	
Interval (Workload Condition)	5	240085.83	48017.17	6.97**
Age by Interval	5	67153.60	13430.72	N.S.
Within Subjects	90	619814.07	6886.82	
Session	2	84283.64	42141.82	6.98**.
Age by Session	2	25058.70	12529.35	N.S.
Within Subjects	36	247477.07	6041.03	
Interval by Session	10	101256.53	10125.65	2.66*
Age by Interval by Session	10	46250.83	4625.08	N.S.
Within Subjects	180	685270.79	3807.06	

*p<.05

**p<.001

Table 43
Means and Standard Deviations for Critical Tracking

	Younger		Older		Overall	
	Mean	SD	Mean	SD	Mean	SD
CD1						
Pre	4.08	.70	3.88	.72	3.98	.70
Post	4.13	.54	4.28	.42	4.20	.48
A1						
Pre	3.99	.66	4.24	.45	4.12	.56
Post	4.05	.61	3.83	.74	3.94	.67
A2						
Pre	4.25	.62	4.29	.56	4.27	.58
Post	4.17	.77	4.28	.66	4.22	.70
D1						
Pre	4.21	.69	4.61	.57	4.41	.65
Post	4.31	.71	4.44	.70	4.38	.69
D2						
Pre	4.53	.64	4.31	.70	4.42	.66
Post	4.39	.69	4.53	.71	4.46	.68
N						
Pre	4.51	.57	4.46	.68	4.48	.61
Post	4.13	1.05	4.19	.73	4.16	.88
CD2						
Pre	4.56	.62	4.41	.58	4.48	.59
Post	4.19	.69	4.74	.62	4.46	.70
CD3						
Pre	4.55	.82	4.57	.65	4.56	.72
Post	4.62	.69	4.74	.64	4.68	.65
CD4						
Pre	4.69	.90	4.85	.86	4.77	.86
Post	4.66	.74	4.71	.81	4.68	.76
CD5						
Pre	4.81	.67	4.72	.57	4.76	.61
Post	4.91	.82	4.93	.77	4.92	.77

Table 44

MANOVA Summary Table for Critical Tracking

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	.40	.40	N.S.
Between Subjects	18	129.54	7.20	
Day of Study	9	24.71	2.75	17.7**
Age by Day	9	.95	.11	N.S.
Within Subjects	162	25.13	.16	
Session	1	.02	.02	N.S.
Age by Session	1	.23	.23	N.S.
Within Subjects	18	3.40	.19	
Day by Session	9	2.36	.26	2.91*
Age by Day by Session	9	2.49	.28	3.08*
Within Subjects	162	14.56	.09	

*p<.05

**p<.001

APPENDIX B

FIGURES

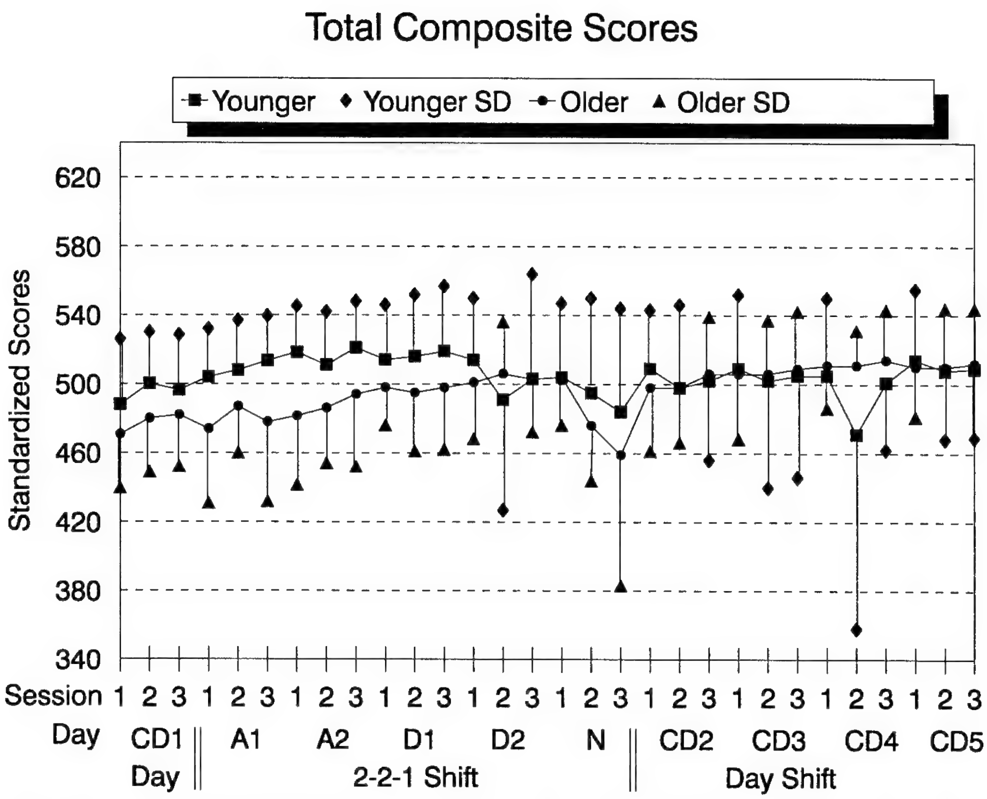


Figure 1. Means and standard deviations for Total Composite Scores by Age group and by Session.

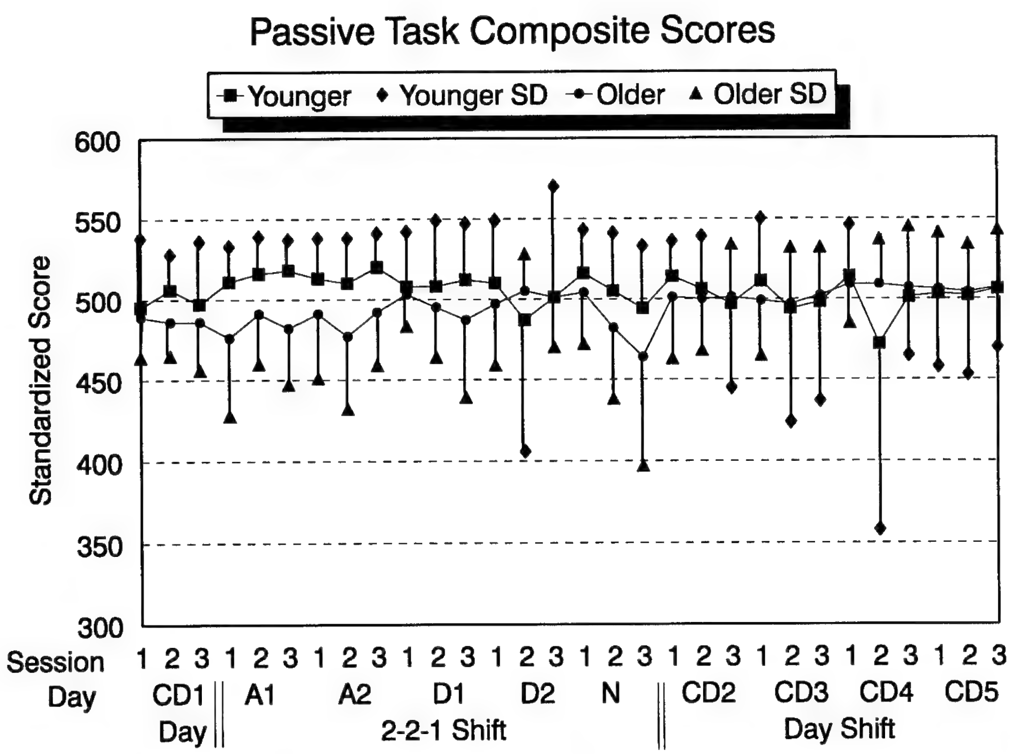


Figure 2. Means and Standard Deviations for Passive Composite Scores by Age group and by Session.

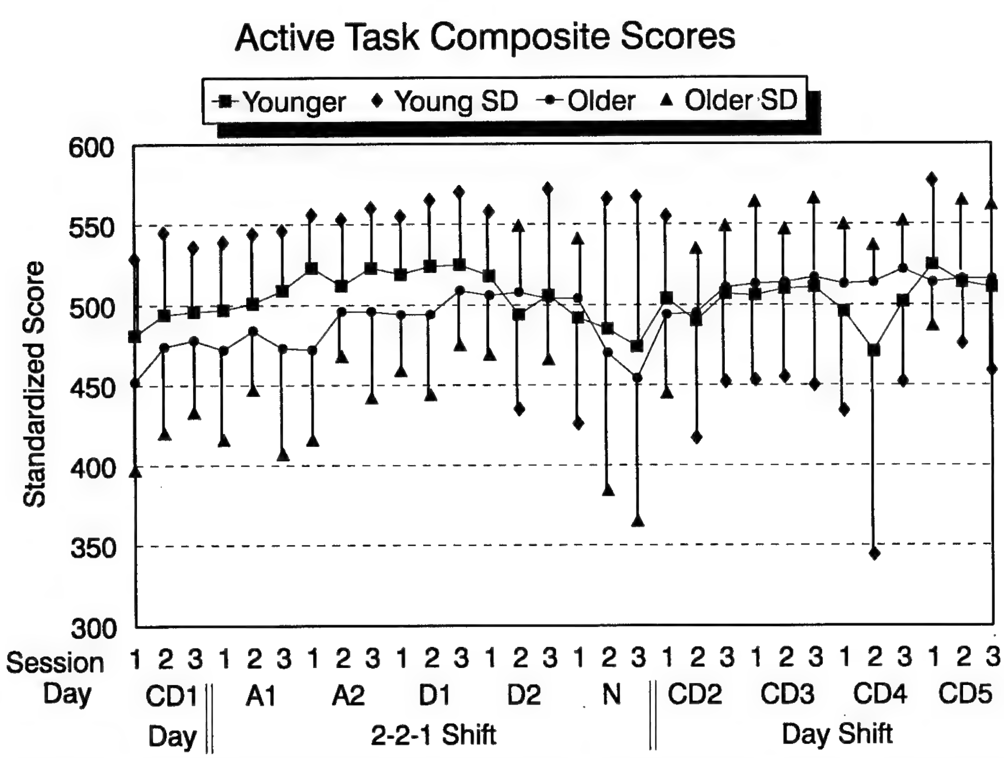


Figure 3. Means and standard deviations for standardized Active Composite Scores by Age group and by Session for those days included in the analysis.

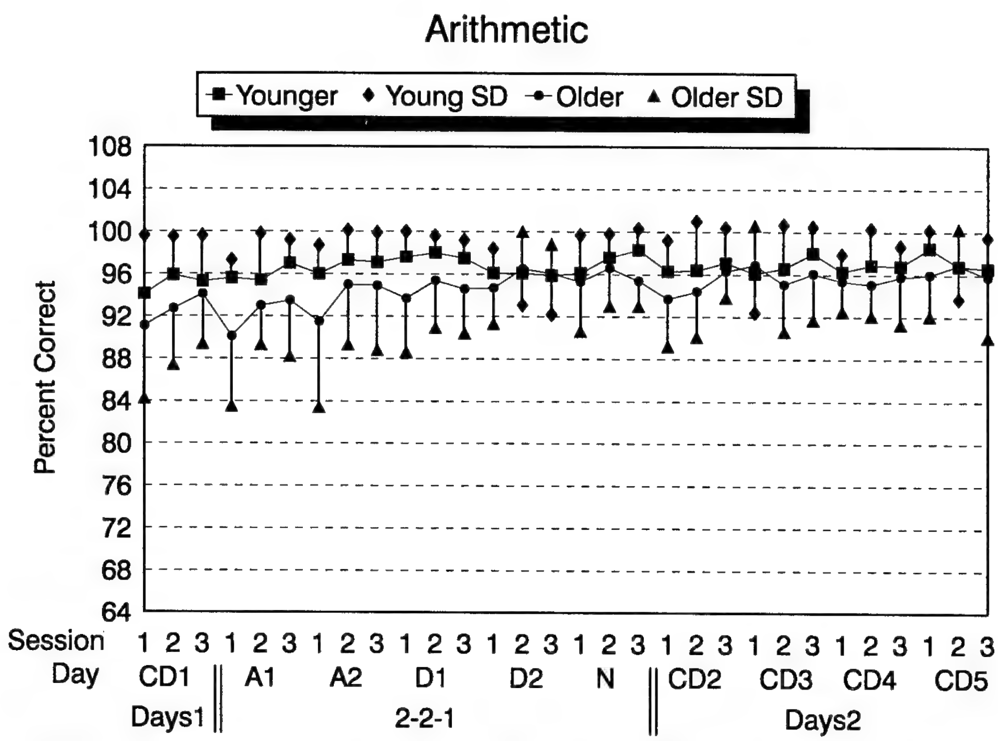


Figure 4. Means and standard deviations for Arithmetic Percent Correct by Age group and by Session.

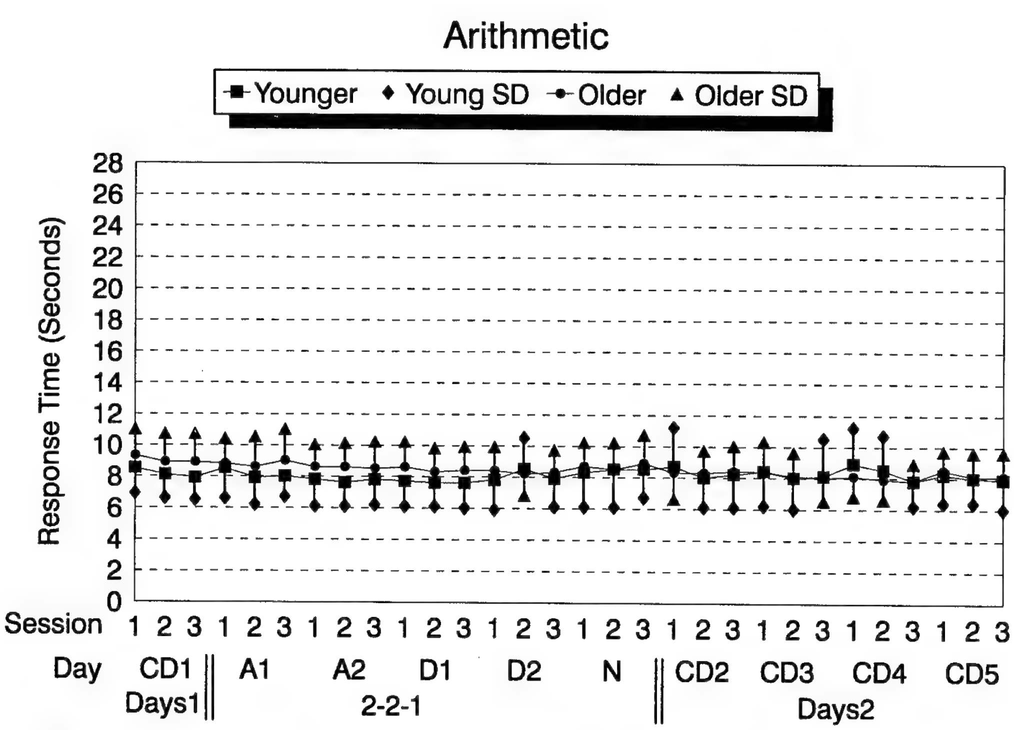


Figure 5. Means and standard deviations for Arithmetic Response Time by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

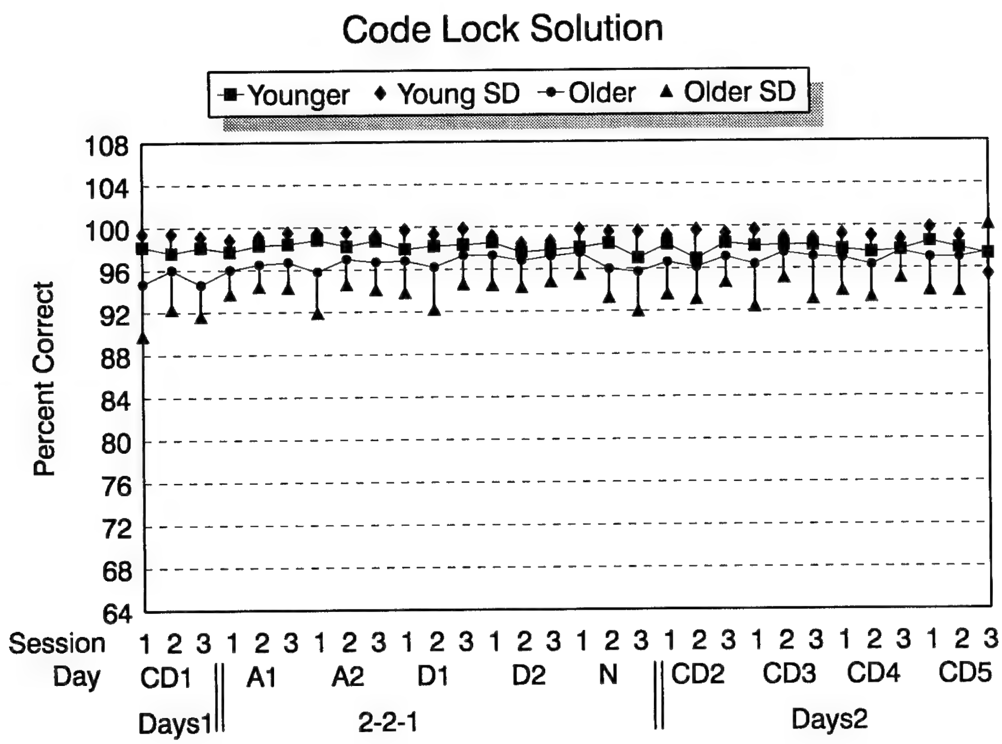


Figure 6. Means and standard deviations for Code Lock Solution Percent Correct by Age Group by Session from day CD1 (week 2) to day CD5 (week 4).

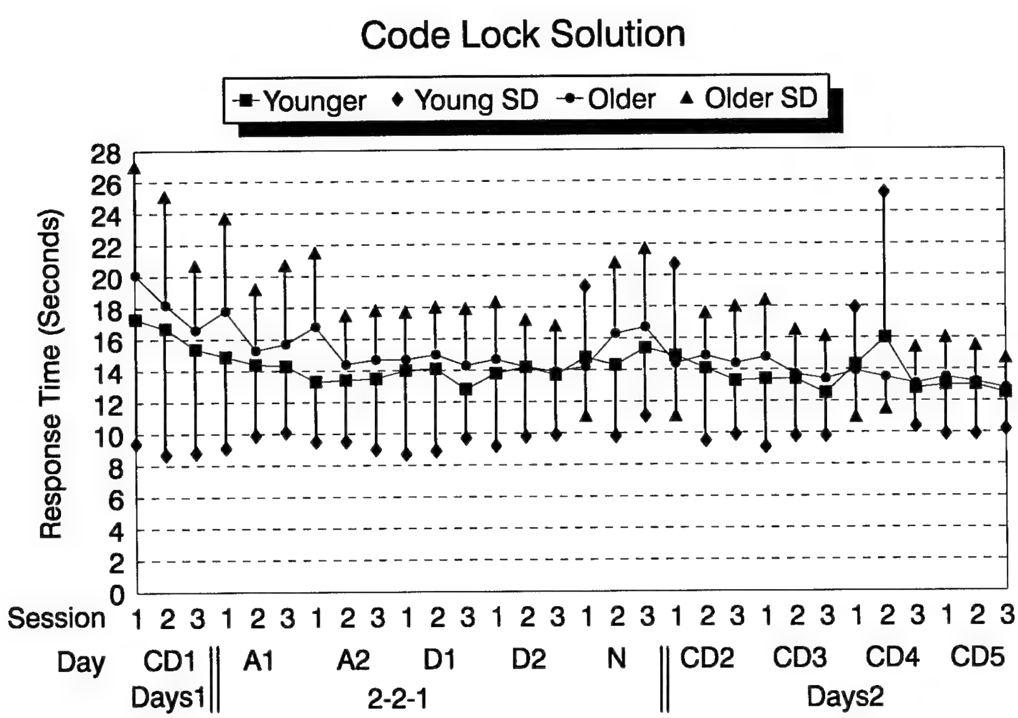


Figure 7. Means and standard deviations for Code Lock Solution Response Time by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

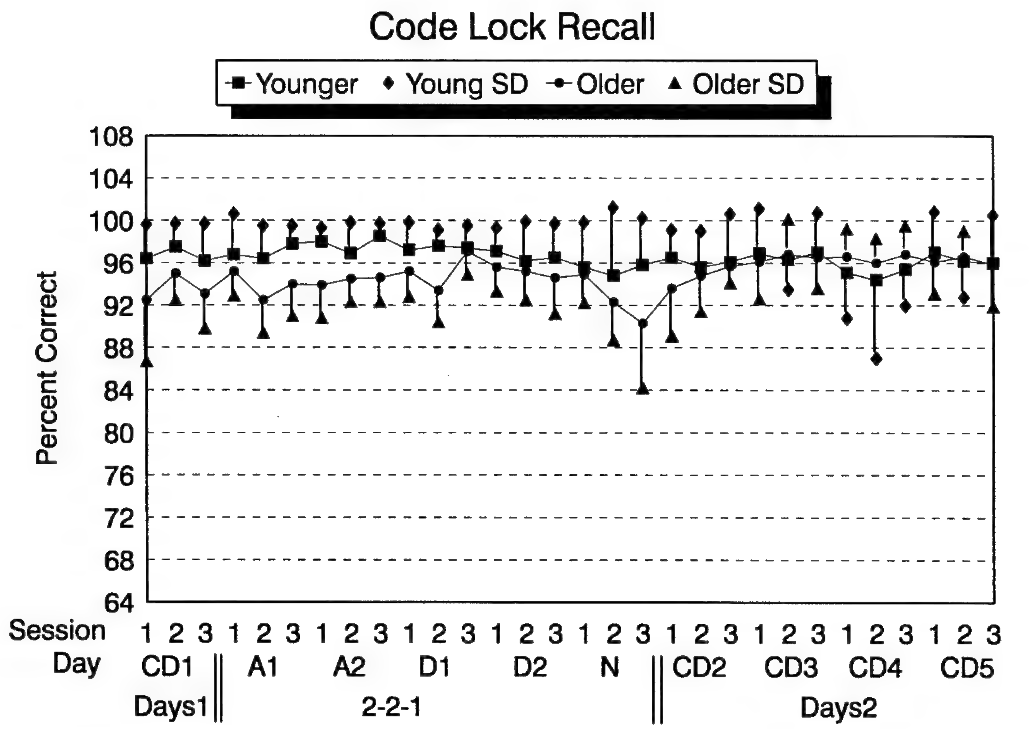


Figure 8. Means and standard deviations for Code Lock Recall Percent Correct by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

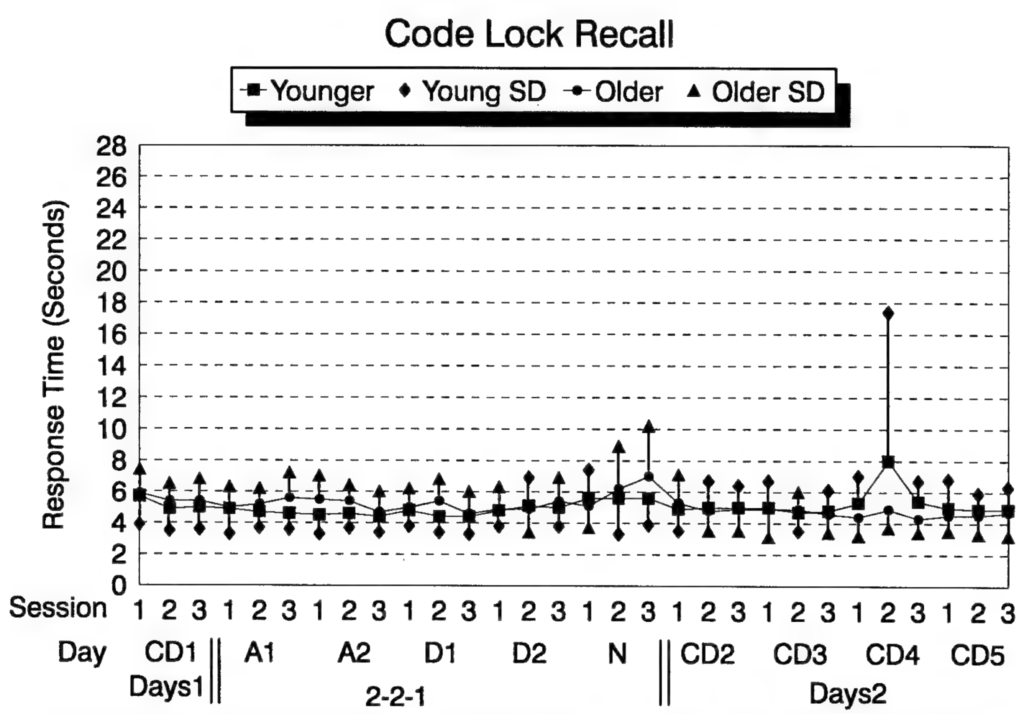


Figure 9. Means and standard deviations for Code Lock Recall Response Time by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

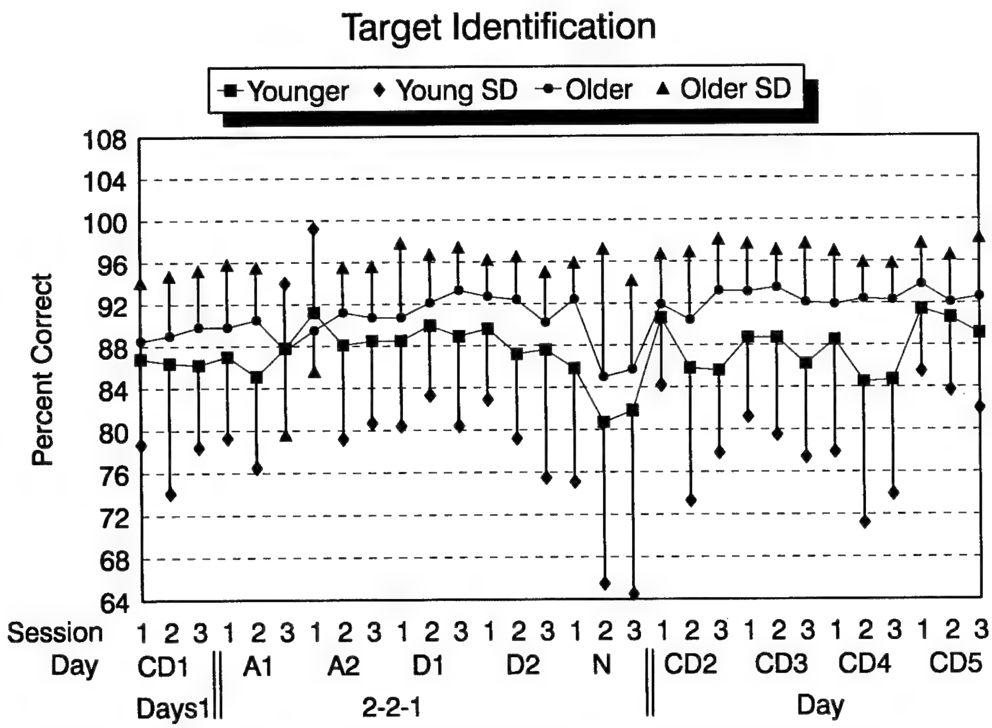


Figure 10. Means and standard deviations for Target Identification Percent Correct by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

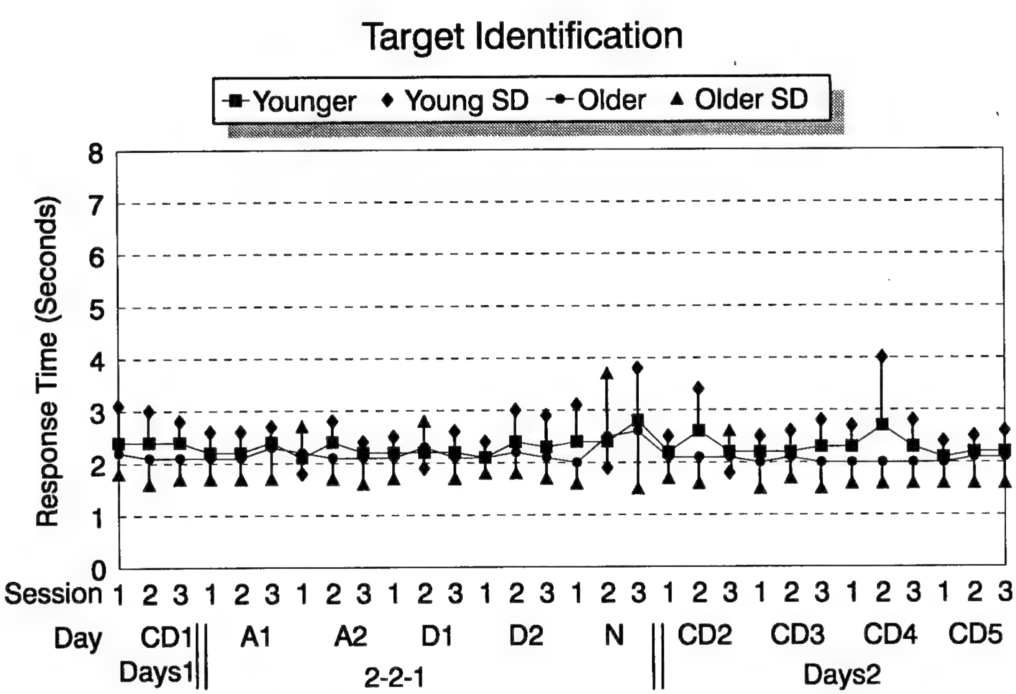


Figure 11. Means and standard deviations for Target Identification Response Time by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

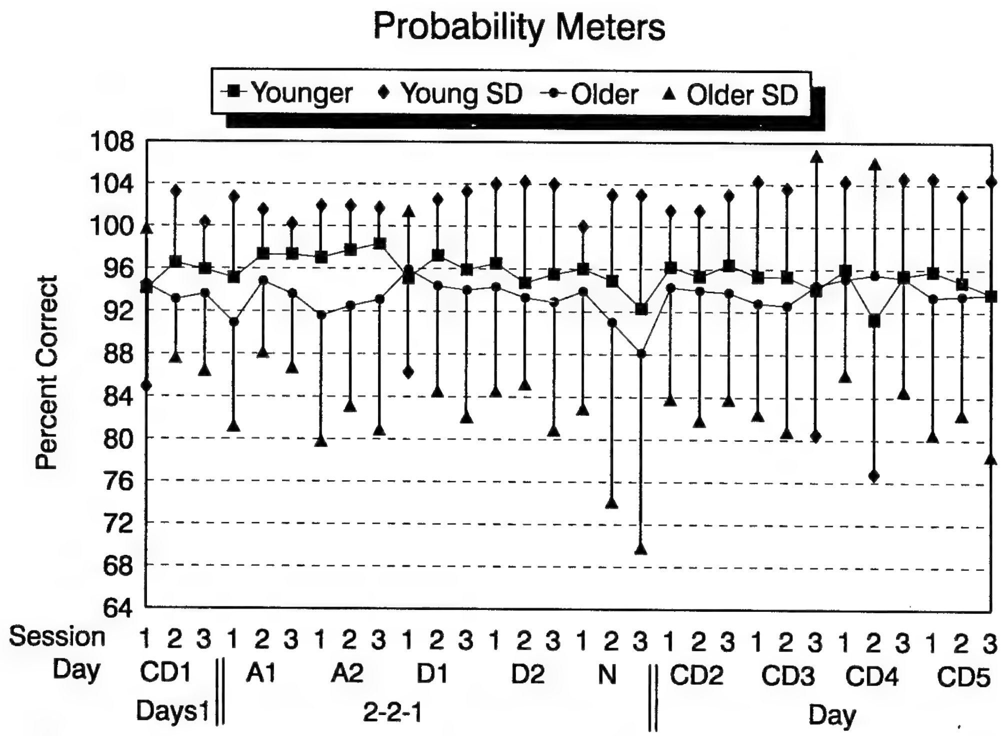


Figure 12. Means and standard deviations for Probability Meters Percent Correct by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

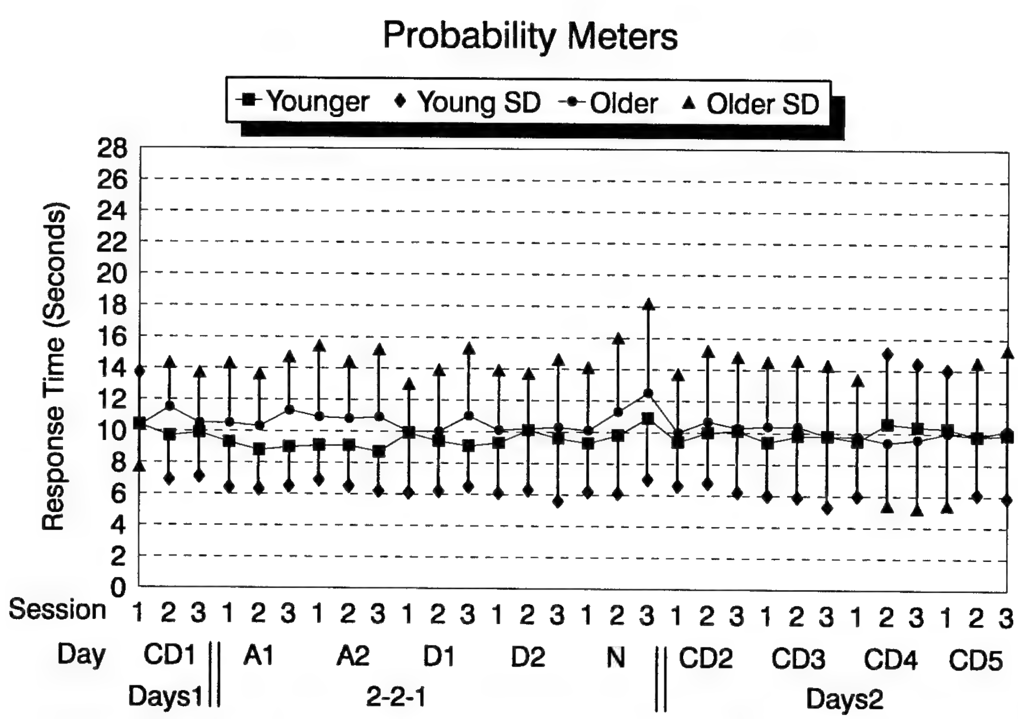


Figure 13. Means and standard deviations for Probability Meters Response Time by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

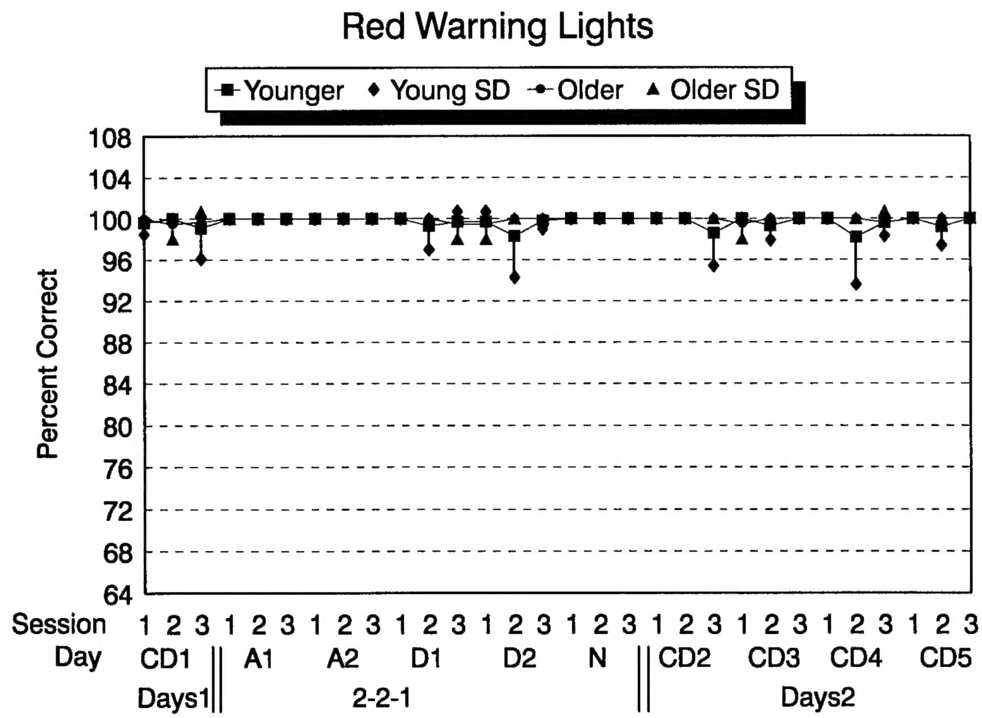


Figure 14. Means and standard deviations for Red Warning Lights Percent Correct by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

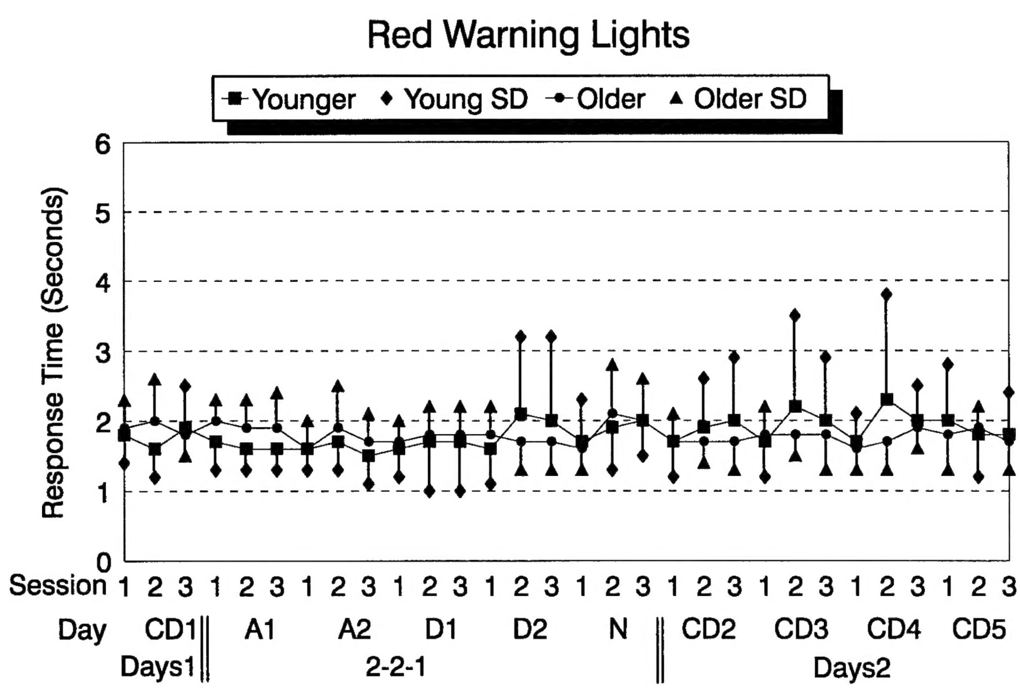


Figure 15. Means and standard deviations for Red Warning Lights Response Time by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

Green Warning Lights

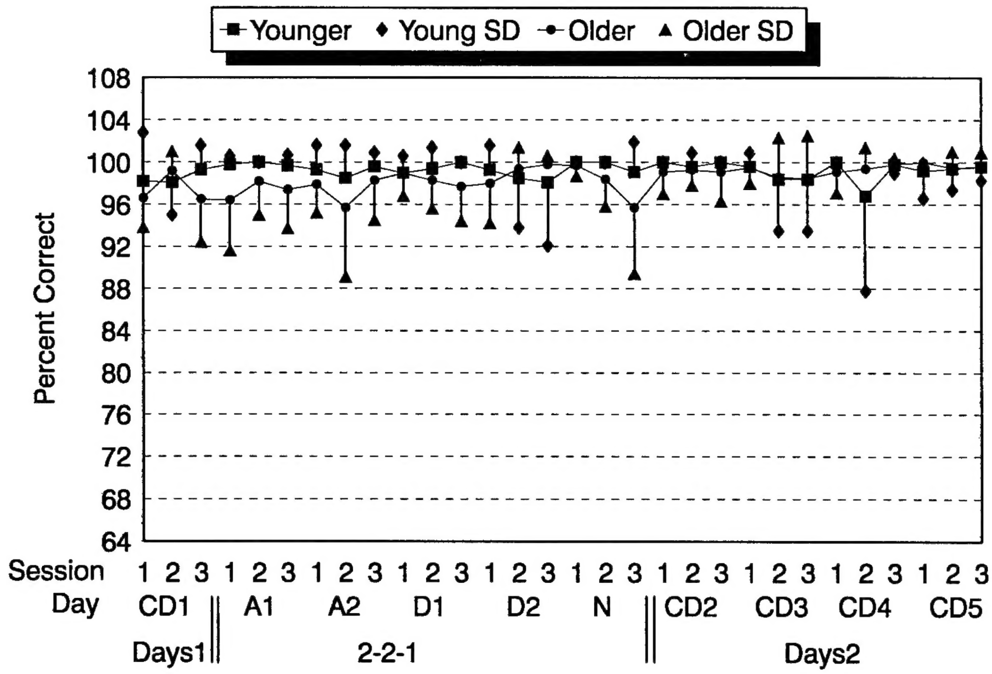


Figure 16. Means and standard deviations for Green Warning Lights Percent Correct by Age group by Session from day CD1 (week 2) to day CD5 (week 4).

Green Warning Lights

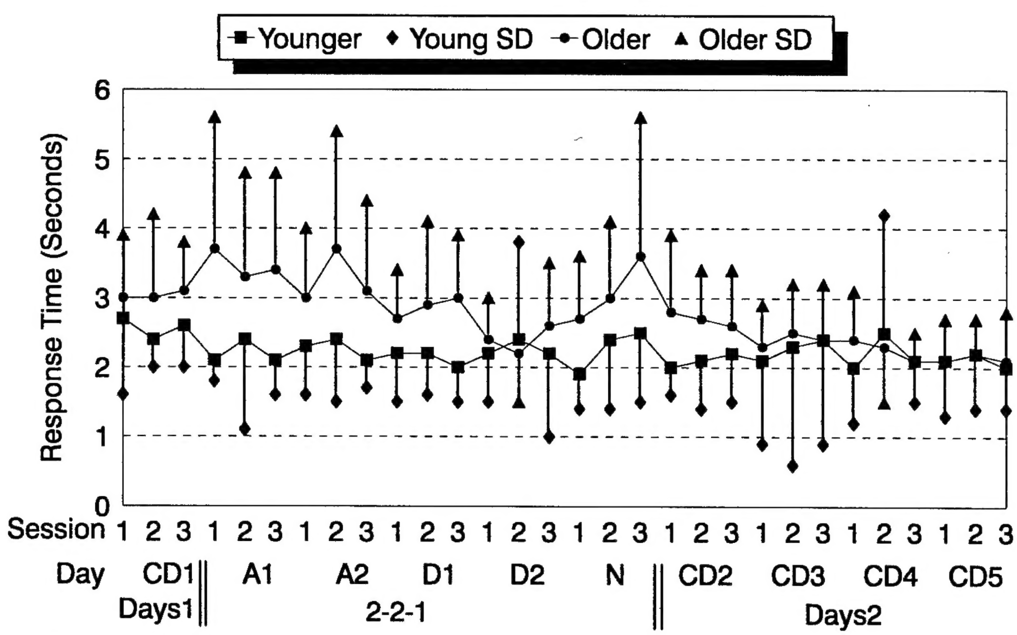
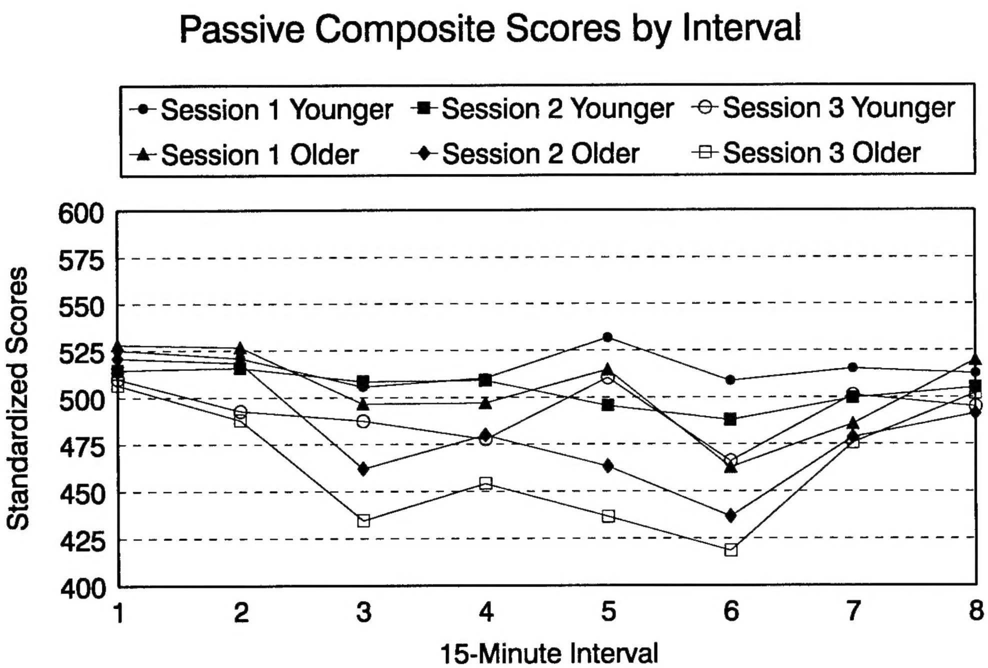


Figure 17. Means and standard deviations for Green Warning Lights Response Times by Age group by Session from day CD1 (week 2) to day CD5 (week 4).



Night Shift

Figure 18. Means of the Passive Composite Scores by Age group and by 15-minute Interval for the three sessions of the Night shift.

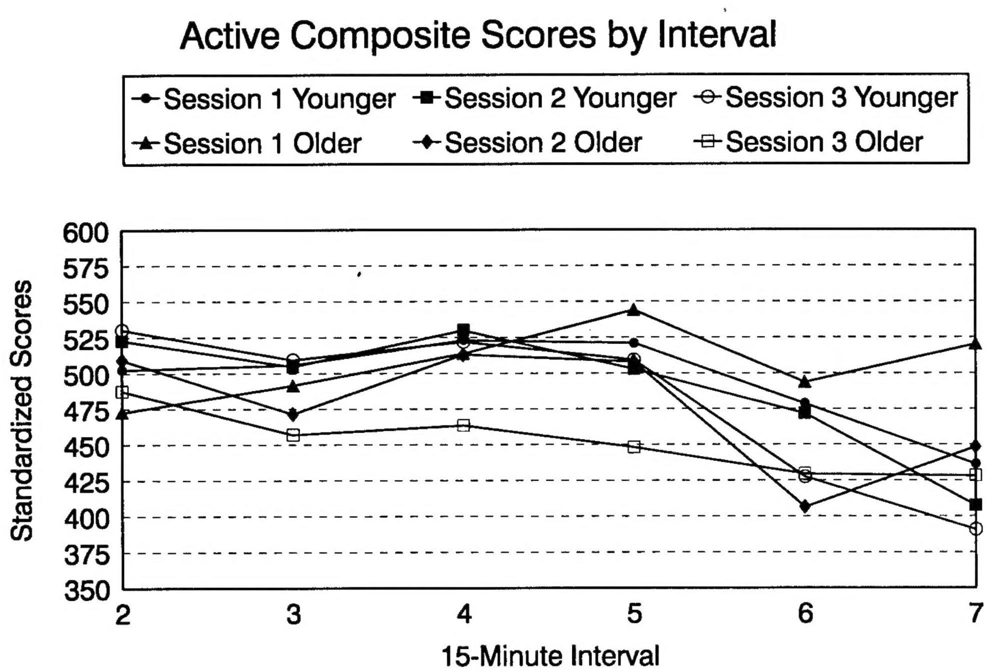


Figure 19. Means of the Active Composite Scores by Age group and by 15-minute Interval for the three sessions of the Night shift.

Critical Tracking

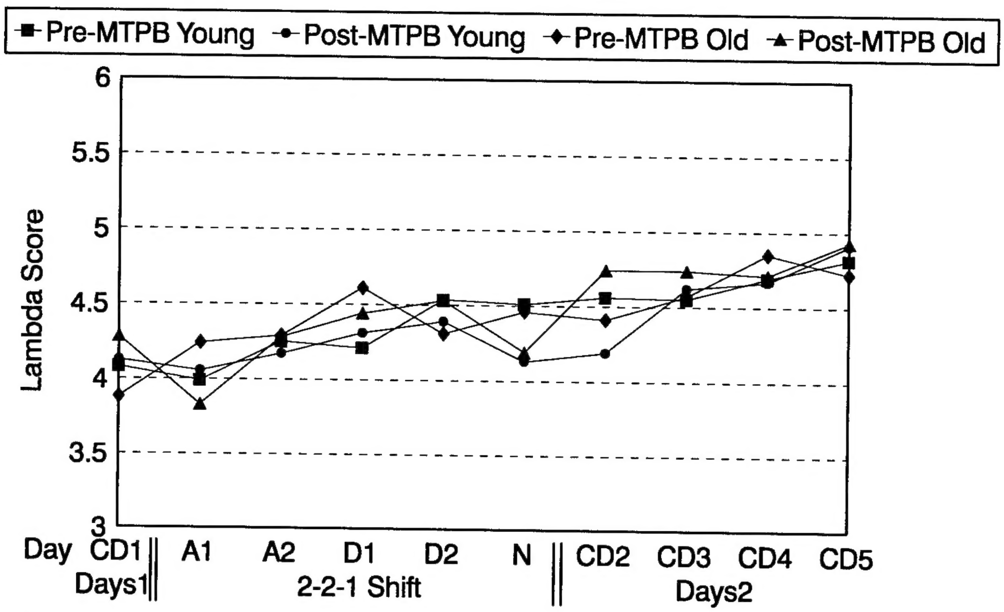


Figure 20. Means for Median Lambda Scores on Critical Tracking by Age Group for Pre- and Post-workday performance from day CD1 (week 2) to day CD5 (week 4).

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